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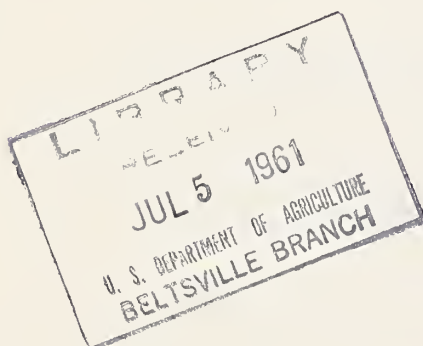
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## POULTRY RESPIRATION CALORIMETRIC STUDIES OF LAYING HENS . . .



- SINGLE COMB WHITE LEGHORNS
- RHODE ISLAND REDS
- NEW HAMPSHIRE X CORNISH CROSS

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# POULTRY RESPIRATION CALORIMETRIC STUDIES OF LAYING HENS . . . . SINGLE COMB WHITE LEGHORNS, RHODE ISLAND REDS, AND NEW HAMPSHIRE X CORNISH CROSS

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## INTRODUCTION

An optimum range of environmental conditions is considered desirable for economical production of eggs. To determine this optimum environmental range, an understanding of the relationship of heat production, physical activity, feather characteristics, and other physiological factors of the hens to weather variables is needed.

A number of references show variation in egg production, size, and quality of eggs with seasonal or temperature changes (2, 3, 9, 12, 13, 20, 24, 26, 27, 28)<sup>2</sup>. To maintain its body temperature, the hen consumes more feed at low temperature and less feed and more water at high temperature (6, 10, 11, 21, 25). At high temperatures, respiration rates stabilize in 8 to 10 days and body temperature in about 3 days (11). Chickens apparently "acclimatize" to high temperature (14), but the breeds differ in tolerance to heat (8, 15, 17). There is some indication that good egg production can be maintained during hot days if night temperatures are sufficiently low (22, 23).

The data on the performance of the hens in this report should not be considered as being fully typical of farm conditions. Age, hatching date, length of testing period, season of the year, and other physiological and physical factors need to be assessed to indicate "acclimatized" performance levels. However, heat and moisture dissipation data were considered sufficiently representative for engineering use.

This report covers a series of heat and moisture measurements of laying hens kept at various controlled temperatures, humidities, light, and ventilation in respiration calorimeters. The studies were made with three breeds of laying hens--Single Comb White Leghorns, Rhode Island Reds, and New Hampshire X Cornish Cross--maintained by the cooperating Poultry Research Branch, Animal Husbandry Research Division, Agricultural Research Service, Beltsville, Md. Tests were conducted with hens in individual cages and with those loose on the floor with litter.

## EXPERIMENTAL EQUIPMENT AND PROCEDURE

### Calorimeters

Two calorimeters, each 7 x 5 x 6 feet high in interior dimensions, were used simultaneously to make heat and moisture measurements of 10 hens in each chamber. Each calorimeter was independently operated and ventilated with metered outdoor air, conditioned to constant dewpoint and dry-bulb temperatures. Generally the ventilation rate was

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<sup>1</sup> Agricultural engineer, Agricultural Engineering Research Division, and Biologist, Animal Husbandry Research Division, Agricultural Research Service, U. S. Department of Agriculture, respectively.

<sup>2</sup> Figures in parentheses refer to Literature Cited at end of this report.

about 1 cubic foot per minute (c.f.m.) per hen. To prevent air stratification in each calorimeter, a small non-oscillating fan provided nearly a mile-per-hour air velocity about the chickens. A cooling coil located near the ceiling of the chamber removed part of the sensible heat (the remainder by ventilation).

The dry-bulb and dewpoint temperatures and heat leakage measurements were continuously monitored. Periodic heat leakage tests of each calorimeter were made by checking against a controlled electrical energy input, equivalent to total heat output of the birds. Over 97 percent of the energy input was accounted for in these checks.

A 15- or 25-watt frosted incandescent lamp in a 12-inch shallow dome reflector was automatically lighted 14 hours a day.

More detailed descriptions of the calorimeters have been published (21, 29).

## Management

Daily feed and water (ad libitum) consumption data were averaged over a 3- to 4-day period. Standard laying mash diet #377 was used as follows:

### COMPOSITION OF DIET #337 (Poultry Research Branch)

<u>Ingredient</u>	<u>Percent Mix</u>
Corn meal	69.2
Soybean oil meal	16.0
Alfalfa meal <sup>1</sup>	5.0
Fish meal	2.0
Steamed bone meal	3.3
Limestone flour	3.0
Riboflavin supplement <sup>2</sup>	.5
Manganized salt	.7
A and D oil <sup>3</sup>	.3

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<sup>1</sup> 17-percent protein dehydrated alfalfa.

<sup>2</sup> 500 micrograms/gram.

<sup>3</sup> 600 units D and 2,250 units A/gram.

The hens in cages were obtained from a selection pool of individually caged hens kept in a laboratory room with windows open as much as possible without freezing water in the room. The hens on litter were picked from a selection pool of hens confined to a range house.

At the beginning of each test, the temperature of the calorimeters was changed from the average ambient condition of the selection pool to the test levels in 3° to 5° F. steps daily. In general, the first 10 days of each test were considered a period of "quieting" the hens to the caretaker and conditions of the calorimeters, although data were taken continuously.

## Calculations

The rate of heat dissipation was calculated from the flow rate and change in psychrometric properties of the ventilation air and from the flow rate and temperature change of the coolant within the ceiling coils (21).

Water input-output balances for 24-hour periods were made by accounting for the following: (a) Metabolic water (19), 44 percent of the wet weight of feed; (b) free and hygroscopic water in the feed; (c) body weight, 65 percent of the hens' average loss or gain in weight; (d) the fountain water input; (e) weight of eggs, 65 percent of the average weight per day of eggs collected during a period 3 to 4 days before and after and including the day of determining heat and moisture balance; (f) the moisture in the fecal matter; (g) moisture removed in the ventilating air; (h) condensation on the cooling coils; and (i) weight of moisture absorbed by wooden equipment in the chambers (with hens on litter).

### Laying Hens in Individual Cages

This series of studies was conducted with 10 laying hens in standard 10-inch wide individual cages in each calorimeter. Each cage was equipped with individual feeder and waterer. At temperature below freezing, a small coil of heating wire was attached to the underside of each insulated fountain to keep water near 35° F. The exposure of 3 x 5 inch water surface was minimized by covering more than half the area with a cork-floated, thin plastic sheet which was hinged to the only open side of the fountain. To prevent "flicking" water into the cages when drinking, each fountain was also hooded with clear plastic and open on one side. Two extra fountains (unavailable to the birds) were placed in each calorimeter to determine evaporation losses. Pans containing sufficient oil to submerge droppings were cleaned out every 3 to 4 days to minimize loss of water and some gases resulting from anaerobic decomposition. Evaporation losses were not determined from (a) bits of fecal matter on wire floor of the cage, and (b) the plastic fountain enclosures, wetted by water flicked off the bills of the hens. However, the cage floor was wire-brushed and the plastic surfaces of the fountain frequently cleaned.

Three breeds and different procedures were used for each of the tests. Within a test, hens were in three groups--Group A was in one calorimeter, Group B in another, and Group C was the control group.

#### Single Comb White Leghorns<sup>3</sup>

On August 10 the pullets, hatched on March 8, were selected from the range house and first put in 3-tiered, battery individual laying cages to calm the hens. A few extra pullets were obtained for possible substitution in case of illness or death of the test hens. With few exceptions, the same hens were kept with their respective groups throughout all tests.

Group A (table 1) hens were exposed to 8 successive temperature levels in 3-week steps (blocks) as follows: 94°, 84°, 74°, 64°, 56°, 47°, 34°, and 26° F.

Group B (table 2) hens were kept from 64° to 67° F., while Group C (table 3) hens were kept with the selection pool of hens in the laboratory room, where the temperature varied from 37° to 85° F.

To conduct test below 64° F., Group A hens were put in Calorimeter B at the start of Block 4, while Group B hens were placed in Calorimeter A. The individual feeders and waterers were transferred along with the birds. Other details of this study have been published (29).

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<sup>3</sup> Dr. W. O. Wilson collaborated on this series of studies while on sabbatical leave from the Poultry Husbandry Department, University of California, Davis, Calif.

TABLE 1.--Calorimeter data of Group A caged Single Comb White Leghorn laying hens

Item	Test block (3 weeks each)								4-week check test
	1	2	3	4	5	6	7	8	
Ambient:									
Temperature.....°F..	94	84	74	64	56	47	34	26	94
Relative humidity.....percent..	69	79	72	69	76	81	86	73	66
Air flow to calorimeter.....lbs./hr..	44.6	45.0	44.3	45.3	44.9	45.6	44.2	45.3	48.8
Hen:									
Average age.....days..	180	200	225	245	268	289	311	335	224
Average weight.....lbs./hen..	3.16	3.10	3.18	3.34	3.55	3.73	3.75	3.72	2.96
Egg production.....percent..	58.5	66.7	64.1	51.8	63.0	54.7	39.2	26.7	44.1
Feed consumption.....lbs./day/10 hens..	1.41	1.87	2.03	2.25	2.27	2.54	2.54	2.51	1.15
Feed conversion.....lbs. feed/lb. eggs..	2.57	2.89	3.07	4.04	3.12	3.82	5.26	7.34	2.51
Water consumption.....lbs./day/10 hens..	6.59	4.87	4.54	4.56	4.98	5.05	4.28	3.31	5.76
Water to feed.....ratio..	4.67	2.60	2.24	2.03	2.19	1.99	1.69	1.32	5.01
Fecal production.....lbs./day/10 hens..	3.62	3.11	3.13	3.37	3.90	4.25	4.10	3.37	3.31
(Water + feed) to feces.....ratio..	2.21	2.17	2.10	2.02	1.86	1.79	1.66	1.73	2.09
Water input-output balance.....lb./10 hens..	<u>+24</u>	<u>+15</u>	<u>+13</u>	<u>+21</u>	<u>+08</u>	<u>+42</u>	<u>+23</u>	<u>+39</u>	<u>+21</u>

TABLE 2.--Calorimeter data of Group B caged Single Comb White Leghorn laying hens

Item	Test block (3 weeks each)								4-week check test
	1	2	3	4	5	6	7	8	
Ambient:									
Temperature.....°F..	64	64	64	65	65	67	66	64	67
Relative humidity.....percent..	68	69	70	69	70	65	67	69	66
Air flow to calorimeter.....lbs./hr..	44.6	44.8	44.9	44.8	45.1	45.1	44.6	45.8	48.3
Hen:									
Average age.....days..	180	201	221	241	270	289	314	334	232
Average weight.....lbs./hen..	3.52	3.53	3.48	3.17	3.52	3.57	3.72	3.69	3.47
Eggs:									
Production.....percent..	62.5	77.6	70.4	51.4	67.5	65.3	60.0	55.7	81.0
Size of eggs.....oz./doz..	18.4	20.4	20.9	20.0	22.2	22.5	23.5	23.2	23.2
Feed consumption.....lbs./day/10 hens..	2.36	2.25	2.31	2.38	2.29	2.38	2.47	2.20	2.43
Feed conversion.....lbs. feed/lb. eggs..	3.75	2.71	3.01	4.17	2.86	3.04	3.36	3.17	2.73
Water consumption.....lbs./day/10 hens..	4.34	4.37	4.56	4.01	4.94	4.72	4.54	3.70	5.66
Water to feed.....ratio..	1.84	1.94	1.97	1.68	2.16	1.98	1.84	1.68	2.33
Fecal production.....lbs./day/10 hens..	3.33	3.33	3.35	3.28	3.68	3.59	3.53	2.89	4.54
(Water + feed) to feces.....ratio..	2.01	1.99	2.05	1.95	1.96	1.98	1.99	2.04	1.78
Water input-output balance.....lb./10 hens..	±12	±15	±16	±16	±18	±30	±58	±34	±36
Heat production:									
Day:									
Latent.....Btu/hr./hen..	10.5	10.6	10.9	7.9	8.6	8.2	7.9	7.3	9.4
Sensible.....do.....	32.7	22.8	23.8	27.0	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	<sup>2</sup> 19.1	23.0
Total.....do.....	43.2	33.4	34.7	34.9	---	---	---	26.4	32.4
Night:									
Latent.....Btu/hr./hen..	8.1	7.6	7.8	5.4	5.8	5.4	5.0	5.9	9.0
Sensible.....do.....	32.7	19.3	20.3	24.2	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	<sup>2</sup> 9.0	22.5
Total.....do.....	40.8	26.9	28.1	29.6	---	---	---	14.9	31.5

<sup>1</sup> Because of instrument failure, no sensible heat obtained.<sup>2</sup> Two hens were molting.

Due to instrument failure, only latent heat was measured during Block 3 of Group A at 74° F., and during test Blocks 5 through 7 of Group B.

During Block 3, on October 15, a hurricane disrupted power from 1 p.m. to 11 p.m. of the same day. When power was restored, the light remained on until 6 a.m., October 16. The lighting time switch for Group C was corrected as soon as the power was restored, but not reset for Groups A and B until the next day.

The following year 4-week check tests were run at 65° and 94° F., with a group of spring-hatched hens. Feeders were cleaned out more often than during the previous year when hens regurgitated water into feeders, and there were difficulties in determining the amount of latent and sensible heats at 94° F.

#### New Hampshire X Cornish Cross

For this test, the Biometrical Services, ARS, suggested the following testing schedule plus one replicate:

##### Trial I

##### Nominal Temperature

<u>Block</u>	<u>Group A Hens</u>	<u>Group B Hens</u>
	°F.	°F.
1	50	30
2	60	20
3	70	40
4	60	30
5	40	20
6	70	50
7	70	60

Each block consisted of a 3-week testing period near the temperature levels indicated and near 75 percent relative humidity (RH). In addition, 10 hens (Group C) were kept in the room with the selection pool of hens.

The tests were started with 342-day-old hens on February 1. The selection of hens for the three groups was based on the egg production 15 days prior to test. There were equal numbers of 10, 11, and 12 egg layers, for each of the three groups. Hens laying soft-shelled eggs prior to testing were not selected. Hens were given at least a 3-week resting period between tests.

The test hens were weighed weekly and artificially inseminated biweekly with pooled sperm of 5 Barred Rock roosters. The roosters were kept with the selection pool hens but in a wire community cage. The eggs were incubated every other week.

On March 1, Test Block 2, the hens were found to have roundworms. Upon recommendation of the Animal Disease and Parasite Research Division, ARS, piprazene hexihydrate was given in the water from March 5 to March 8, inclusive. There were no power or equipment failures during this test.

## Rhode Island Reds

For this study, the following accelerated test schedule was suggested by ARS Biometrical Services.

### Trial I

#### Nominal Temperature

<u>Block</u>	<u>Group A Hens</u> °F.	<u>Group B Hens</u> °F.
1	92	59
2	42	25
3	92	76
4	76	25
5	59	42

Each replicate was designed to cover the first egg-laying cycle of the hens. A control group (C) of 10 hens was used similar to test with caged New Hampshire X Cornish Cross.

The design also called for one replicate series of tests but the replicate (Trial II) was not run.

The hens were selected on the basis of egg production as for the caged New Hampshire X Cornish Cross. All hens were given at least one 3-week rest period between tests. When the temperature was above 90° F., the hens were given at least 6 weeks of rest. The three groups were weighed weekly and artificially inseminated biweekly with pooled sperm from 6 Single Comb White Leghorn roosters. The roosters were kept with selection pool of hens but in wire community cages. The eggs were incubated weekly.

In tests at 92° F. a small 7-1/2-watt white-frosted incandescent lamp was lighted continuously so that hens could see the fountains at night. Also, the feed pans were serviced more often during the day to minimize fermentation of feed.

### Laying Hens on Litter

Each calorimeter was equipped with a standard 3-foot metal feeder and a round 4-gallon fountain. At low temperatures the fountain was set in an insulated box containing a small incandescent lamp. An experimentally determined evaporation loss from the fountain was applied. A collar of 1/4-inch hardware cloth, with slotted openings large enough to permit hens to drink with minimum wetting of the wattles, covered the drinking surface. Roosts along with 3 wooden nests were located over a droppings table.

One-inch wooden flooring was used to keep litter off the metal calorimeter floor. The litter consisted of jack pine and oak sawdust. It was sampled for moisture and occasionally stirred; superphosphate (SP) was added to control ammonia. When dry litter was needed for Calorimeter B to replace wet litter, the dry litter from Calorimeter A (at higher temperature) was used so that decomposition could continue. New litter was added to Calorimeter A.

The laying hens for these tests were selected by the poultry scientists on the basis of good physical appearance and laying condition.

Tests with Single Comb White Leghorns were not conducted on litter.

### Rhode Island Reds

Tests were started with 320-day-old chickens in January. The general scheme of testing was to keep Calorimeter A near 90° F. and Calorimeter B at temperatures near 20° F.

Near the end of the test, the hens were switched between calorimeters to obtain some physiological inferences. The hens were switched on June 1 when both calorimeters were at 65° F. Because of warm weather, Calorimeter B could only be operated at about 30° F. The tests were terminated on June 19.

From March 30 to May 22, eggs were collected every 2 hours during the day to make Haugh-unit determinations.

### New Hampshire X Cornish Cross

Tests were begun on November 1 on 237-day-old hens. The two calorimeters were run simultaneously, one near 65° F. and 75 percent relative humidity, and the other at 75° F. and 75 percent relative humidity.

In addition to the usual measurements, few gravimetric checks were made on the amount of ammonia gas in the air by using a standard chemical procedure with a metered amount of calorimeter air.

## RESULTS

The discussions will be mostly on heat and moisture production and those data that may be used to study manure accumulation and litter moisture changes. For convenience in comparing the heat production data of caged hens on-litter having different average body weights, the sensible and total heat were adjusted to various nominal body weights. This was accomplished by multiplying a ratio, average test condition body weight divided by the nominal body weight, by the average heat data.

The latent heat data were not differentiated according to body weights as there was little difference in latent heat output of hens of different body weights.

In general, the control or Group C hens were least affected by weather variable. Perhaps the psychological reaction to being near and visible to the selection pool of hens, the day and night temperature fluctuations, and other factors may have had some beneficial effects. The test data on the various groups of hens were obtained during the time that heat and moisture measurements were determined.

### Caged Laying Hens

#### Single Comb White Leghorns

Heat and Moisture Production. --The heat production of Group A, the variable temperature group, is shown in Appendix Figure 1. Since the sequence of testing was from highest to lowest temperature, age and acclimatization effects were possibly inherent.

As ambient temperatures were reduced below 85° F., the day sensible heat tended to stabilize until about 45° F., at which time it again began to increase with decreasing temperatures. The hens were apparently able to maintain a constant rate of heat dissipation between 85° and 45° F. Perhaps this could be considered a "comfortable" range of temperature.

Below 45° F. the hens became inactive, fluffed their feathers, and frequently had their heads under their wings. At the highest temperatures, the hens remained awake most of the night and drank water continually.

Both day and night latent heat generally decreased with decreasing temperature, dropping to about 6 Btu per hen at 26° F.

Within a temperature condition, the latent heat varied about 1 Btu or less from the mean, and sensible heat varied as much as 15 to 25 percent of the mean. These variations were probably due to physical activities of the hens and the specific dynamic action of the consumed feed.

Table 2 shows that both sensible and latent heat of Group B, held near 65° F., decreased with age. Dukes (5), Mitchell (18), and Kibler (16) showed that basal metabolism of laying hens decreased with age.

Hen Performance Data. --The performance and test conditions for the three groups of hens are shown in Tables 1, 2 and 3.

TABLE 3.--Data of Group C caged Single Comb White Leghorn laying hens

Item	Test block (3 weeks each)							
	1	2	3	4	5	6	7	8
Ambient:								
Temperature..... °F..	70-84	67-85	62-85	53-70	45-58	39-55	43-54	37-54
Relative Humidity..... percent..	50-85	50-85	40-65	40-65	40-65	40-65	30-50	30-50
Hen:								
Average age..... days..	180	201	223	248	272	291	312	334
Average weight..... lbs./hens..	3.52	3.44	3.30	3.41	3.57	3.71	3.76	3.75
Eggs:								
Production..... percent..	72.0	78.6	72.3	59.3	62.0	69.4	60.4	54.7
Size of eggs..... oz./doz..	18.3	19.4	20.4	21.5	22.3	23.3	23.6	23.8
Feed consumption..... lbs./day/10 hens..	2.15	2.07	2.12	2.27	2.51	2.51	2.49	2.47
Feed conversion..... lbs. feed/lb. eggs..	3.13	2.61	2.76	3.42	3.49	2.98	3.35	3.64
Water consumption..... lbs./day/10 hens..	4.06	4.28	4.72	4.56	4.78	5.71	5.05	4.34
Water to feed..... Ratio..	1.89	2.07	2.23	2.01	1.90	2.27	2.03	1.76

Table 4 shows that 54 percent of the total water output of Group A hens at 94° F. was respired or ventilated. This percentage decreased to about 30 percent at 26° F. About one-third of total water output from Group B (more than 220 days of age) was respired at 65° F.

The moisture content of feces was about 75 percent on a wet basis for all temperatures. Further information regarding this test has been published (29).

TABLE 4.--Water output from Single Comb White Leghorn hens at various temperatures and ages

Group A. Water output/day/10 hens							Group B. Water output/day/10 hens						
Average age	Temperature	Ventilated	Eggs	Feces	Total	Ventilated total	Average age	Temperature	Ventilated	Eggs	Feces	Total	Ventilated total
Day	°F.	Lbs.	Lbs.	Lbs.	Lbs.	Ratio	Day	°F.	Lbs.	Lbs.	Lbs.	Lbs.	Ratio
180	94	3.52	0.36	2.62	6.50	0.54	180	64	2.13	0.50	2.49	5.12	0.42
<sup>1</sup> 224	94	2.76	.30	2.48	5.54	.50	201	64	2.04	.55	2.63	5.22	.39
200	84	2.68	.42	2.39	5.49	.49	221	64	2.10	.50	2.48	5.08	.41
225	74	1.98	.45	2.39	4.82	.41	241	65	1.50	.30	2.09	3.89	.39
245	64	1.71	.35	2.51	4.57	.37	270	65	1.62	.50	2.71	4.83	.34
268	56	2.33	.48	2.86	5.67	.41	<sup>1</sup> 232	67	2.03	.64	3.40	6.07	.33
289	47	1.75	.42	3.22	5.39	.32	289	67	1.53	.52	2.72	4.77	.32
311	34	1.72	.33	3.09	5.14	.33	314	66	1.46	.55	2.70	4.71	.31
335	26	1.23	.23	2.60	4.06	.30	334	64	1.47	.42	2.28	4.17	.35

<sup>1</sup> Check tests conducted later with different groups of 10 Single Comb White Leghorn hens.

### Rhode Island Reds

Heat and Moisture Production. --The data from Groups A and B were averaged and are shown in Appendix figure 2 and in table 5. As air temperature increased from about 28° to 40° F., day sensible heat increased and thereafter decreased with increasing temperatures. The relatively low day sensible heat values at about 25° F. were attributed to fluffing of feathers and inactivity at that temperature. The "comfort" zone that was shown in the caged Leghorn data was not sharply defined among these caged Rhode Island Reds, but night total heat was practically constant between 28° and 60° F.

Both day and night latent heat remained relatively constant from about 40° to 80° F., increasing above 80° F. and decreasing at some temperature below 40° F. Near 28° F. both day and night values were about 6 Btu/hr/hen.

The day to day change within each temperature condition was plus or minus 1 to plus or minus 5 Btu/hr/hen for both day and night sensible heat. However, the latent heat remained almost constant.

Appendix figure 3 shows that about 35 percent of the total water output is respired water between temperatures of about 40° and 75° F., while at 92° F. the amount may be more than 50 percent depending on age and perhaps egg production. At 92° F. there was 6 lbs./day/100 hen difference in respired moisture between hens producing 65 and 23 percent eggs. However, age may also be a factor as younger hens produced 21 percent more respired water while laying 42 percent more eggs than older hens in a replicate test. Of the 34 pounds per day per 100 hens difference in water output of the two age groups, only 2.8 pounds were eggs, while the remaining 31.2 pounds were accounted for by defecation and respiration.

Hen Performance Data. --Tables 5, 6 and 7 show the performance data of the caged Rhode Island Reds. Table 5 shows that hens that laid eggs near 75 percent production rate had good feed conversion of about 3.1 lbs. of feed/lb. of eggs at temperatures between 25° and 76° F. The feed conversion rates at other temperature and egg production levels were comparable to published data of Rhode Island Reds on litter (21). The test data between 40° and 60° F. and 75 percent egg production agree well with Ewing's feed conversion data (7). At 92° F. Ewing's data, which are based on year-round average, were 100 percent greater and at 31° F. were 13 percent lower than test data.

The average water consumption rate from 25° to 76° F. was about 5.0 lbs./day for 10 hens, which were laying at a 50 to 75 percent production rate. At 92° F. the 10 hens (laying 65 percent) drank almost 7-1/3 lbs./day, but when laying at the rate of 23 percent drank only 4 lbs./day.

TABLE 5.--Calorimeter data of caged Rhode Island Red laying hens (Groups A and B)

Item	Month of test									
	Dec.	Jan.- Feb.	Jan.- Feb.	Feb.- Mar.	Dec.	Mar.	Jan.	Mar.	Jan.	Feb.- Mar.
Ambient										
Temperature.....°F..	92	92	76	76	60	60	45	41	25	31
Relative humidity.....percent..	46	36	50	60	70	64	83	85	70	85
Air flow to calorimeter.....lbs./hr..	43.8	44.7	46.0	45.8	47.1	45.7	45.2	48.1	45.7	46.6
Hen										
Average age.....days..	230	282	286	300	228	321	261	321	261	303
Average weight.....lbs./hen..	4.95	4.95	5.31	5.60	5.65	5.60	5.78	5.56	5.49	5.63
Eggs										
Production.....percent..	65	23	75	66	76	50	86	75	76	46
Size of eggs.....oz./doz..	20.3	21.9	22.5	22.6	22.4	23.8	23.8	23.5	23.5	24.0
Feed consumption.....lbs./day/10 hens..	1.40	1.00	2.69	2.46	2.96	2.49	3.00	2.84	2.90	2.91
Feed conversion.....lbs. feed/lb. eggs..	2.04	3.81	3.06	3.17	3.34	4.02	2.81	3.09	3.12	5.06
Water consumption.....lbs./day/10 hens..	7.29	4.01	5.07	4.86	5.14	4.80	5.82	4.66	4.84	4.60
Water to feed.....ratio..	5.21	4.01	1.88	1.98	1.74	1.93	1.94	1.64	1.67	1.58
Fecal production.....lbs./day/10 hens..	4.61	2.14	4.52	4.01	5.20	4.20	5.29	4.29	4.73	4.50
(Water + feed) to feces.....ratio..	1.89	2.34	1.72	1.83	1.56	1.74	1.67	1.75	1.64	1.67
Water input-output balance.....lb./10 hens..	+38	+32	+41	+56	+15	+19	+17	+12	+40	+20
Heat production:										
Day										
Latent.....Btu/hr./hen..	17	14	13.5	10	12	11	10.4	10.6	6.7	7.5
Sensible.....Btu/hr./hen..	16	<sup>1</sup> -1	13.0	30	40	34	43	40.7	31	41
Total.....Btu/hr./hen..	33	13	26.5	40	52	45	53.4	51.3	37.7	48.5
Night										
Latent.....Btu/hr./hen..	13	11.2	10.2	6.7	8.0	7.8	8.9	8.4	6.3	7.0
Sensible.....Btu/hr./hen..	7	0.8	8.3	19.6	36.2	24.0	21.0	28.0	24.0	29.0
Total.....Btu/hr./hen..	20	12	18.5	26.3	44.2	31.8	29.9	36.4	30.3	36.0

<sup>1</sup> Since magnitude of sensible heat production is small at high temperatures, small errors in determining evaporation losses from fountains and regurgitated water in the feeders may account for the negative value.

TABLE 6.--Data on Group C caged Rhode Island Red hens

Item	Test block				
	1	2	3	4	5
Ambient:					
Temperature.....°F..	67	61	70	72	71
Relative humidity.....percent..	44	55	57	53	53
Hen:					
Average age.....days..	230	259	280	301	321
Average weight.....lbs./hen..	5.7	5.8	5.7	5.7	5.6
Egg:					
Production.....percent..	91	83	83	59	72
Size of eggs.....oz./doz..	23.2	24.7	23.9	23.6	23.6
Feed consumption.....lbs./day/10 hens..	3.09	3.18	2.89	2.32	2.68
Feed conversion.....lbs. feed/lb. eggs..	2.81	2.98	2.80	3.20	3.02
Water consumption.....lbs./day/10 hens..	6.22	6.16	6.16	4.81	5.49
Water to feed.....ratio..	2.01	1.94	2.13	2.07	2.05
Fecal production.....lbs./day/10 hens..	5.47	5.35	5.07	3.95	4.58
(Water + feed) to feces.....ratio..	1.70	1.75	1.79	1.81	1.78

The ratio of water to feed remained 1.6-1.9 to 1 between 25° and 75° F. At 92° F., the ratio was 4.0 to 1 for hens laying at 23 percent and 5.2 to 1 for 65 percent production.

The fecal production ranged from 4.0 to 5.3 lbs./day for 10 hens between temperatures of 25° to 92° F. Only 2.1 pounds were produced by hens laying at the 23 percent production rate at 92° F. The average moisture content of feces was about 82 percent on a wet basis for all temperature levels between 25° to 75° F., and near 90 percent for hens at 92° F.

Between 25° and 75° F. the ratio of feed and water to fecal production increased almost linearly from about 1.7 to 1, and then up to about 2.3 to 1 at 92° F.

TABLE 7.--Egg data of caged Rhode Island Red laying hens, before, during, and after each test

Test block	Group	Before		During				After	
		Tempera- ture	Egg pro- duction	Tempera- ture	Egg pro- duction	Fertility	Hatch- ability	Tempera- ture	Egg pro- duction
		°F.	Pct.	°F.	Pct.	Pct.	Pct.	°F.	Pct.
1	A		81	93	69	68	59		78
	B	61	81	59	76	89	79	62	94
	C		83	67	91	94	77		95
2	A		88	42	85	96	82		73
	B	62	88	25	83	95	87	69	70
	C		88	61	83	99	92		73
3	A		91	93	23	91	81		33
	B	61	91	76	79	86	67	73	72
	C		91	70	83	95	78		79
4	A		86	76	68	100	68		70
	B	57	86	33	57	91	67	73	64
	C		86	72	59	89	40		54
5	A		79	59	50	51	27		63
	B	72	79	42	70	83	38	73	51
	C		72	71	72	89	58		73

The data for Group C hens are shown in table 6.

Table 7 shows that the technique of insemination and the pooling of the semen were good. With the exceptions of test blocks 2 and 4, Group C maintained the best egg production during the testing period.

During the two tests at 92° F. (appendix figure 4) the hens lost more than 1 pound each in 10 to 14 days. Two of the heaviest hens (6.5 and 6.8 pounds) died on the fifth day at 92° F. and 46 percent relative humidity in the first test. But in the second test at 92° F. and 36 percent relative humidity, one hen, heaviest at the start of test weighing 6.2 pounds, died on the eighteenth day with a loss of 0.7 pounds. Thus 92° F. and 36 percent relative humidity is uncomfortable for these hens. The average weight of hens at other temperature levels declined slightly within the first week of test.

#### New Hampshire X Cornish Cross

Heat and Moisture Production. --Between ambient temperatures of 40° and 60° F. (appendix figure 5), both day and night sensible heat from caged New Hampshire X Cornish Cross hens tended to stabilize. Below 40° F. sensible heat increased sharply. Thus the lower end of the apparent "comfort" zone may be near 40° F., while the upper end may be between 60° and 70° F.

Both day and night latent heats were nearly constant between 40° to 70° F. Below 40° F., the latent heat decreased. Night values of both latent and sensible heat were consistently less than day values.

Appendix figure 6 shows that the percent of the total water output dissipated as respiratory moisture was about 25 percent between 20° and 32° F., and about 32 percent between 40° and 70° F. Again, as in the case of Rhode Island Red tests, the relationship between the amount of respired moisture and egg production was slight.

Hen Performance Data. --The performance and test conditions for the three groups of hens are shown in appendix figures 6 and 7 and in tables 8, 9 and 10.

TABLE 8.--Calorimeter data of caged New Hampshire X Cornish Cross laying hens (Groups A and B)

Item	Month of test						
	Mar.-Apr.	May-June	June-July	Feb.-Mar.	Apr.	June-July	Feb.
Ambient:							
Temperature.....°F..	71	70	71	62	61	61	52
Relative humidity.....percent..	70	65	61	75	66	59	81
Air flow to calorimeter.....lbs./hr..	50.3	49.4	49.2	49.6	50.7	49.1	47.0
Hen:							
Average age.....days..	399	464	485	373	422	488	356
Average weight.....lbs./hen..	6.89	6.94	6.95	6.98	7.07	6.77	6.96
Eggs:							
Production.....percent..	62	59	50	71	67	51	72
Size of eggs.....oz./doz..	26.7	27.4	27.7	27.1	27.0	27.5	26.1
Feed consumption.....lbs./day/10 hens..	2.57	2.61	2.61	3.01	2.74	2.54	3.07
Feed conversion.....lbs. feed/lb. eggs..	2.98	3.10	3.61	3.00	2.91	3.48	3.14
Water consumption.....lbs./day/10 hens..	4.42	4.81	5.07	5.30	5.14	3.90	4.72
Water to feed.....ratio..	1.72	1.84	1.94	1.76	1.88	1.54	1.54
Fecal production.....lbs./day/10 hens..	4.24	4.24	4.49	5.00	4.64	3.87	4.67
(Water + feed) to feces.....ratio..	1.65	1.75	1.71	1.66	1.70	1.66	1.67
Water input-output balance.....lb./day/10 hens..	±.35	±.28	±.38	±.28	±.28	±.08	±.09

Item	Month of test						
	May-June	Mar.-Apr.	May	Feb.	Apr.	Feb.-Mar.	May
Ambient:							
Temperature.....°F..	50	43	44	32	31	21	23
Relative humidity.....percent..	66	71	82	71	70	69	76
Air flow to calorimeter.....lbs./hr..	49.0	49.5	47.5	48.7	48.6	49.0	49.5
Hen:							
Average age.....days..	465	398	443	358	421	375	442
Average weight.....lbs./hen..	6.88	6.90	6.96	6.96	6.53	6.55	6.44
Eggs:							
Production.....percent..	60	57	60	73	55	61	52
Size of eggs.....oz./doz..	27.4	28.2	27.2	27.5	26.1	28.0	27.0
Feed consumption.....lbs./day/10 hens..	2.67	2.51	2.44	2.77	2.31	2.48	2.38
Feed conversion.....lbs. feed/lb. eggs..	3.12	3.00	2.87	2.65	3.09	2.79	3.25
Water consumption.....lbs./day/10 hens..	4.35	3.70	3.97	4.36	3.38	3.42	3.44
Water to feed.....ratio..	1.63	1.47	1.63	1.57	1.46	1.38	1.45
Fecal production.....lbs./day/10 hens..	4.07	3.33	3.76	4.64	3.49	3.68	3.55
(Water + feed) to feces.....ratio..	1.72	1.86	1.70	1.54	1.63	1.60	1.64
Water input-output balance.....lb./day/10 hens..	±.19	±.17	±.19	±.23	±.21	±.13	±.14

TABLE 9.--Data of Group C caged New Hampshire X Cornish Cross laying hens

Item	Test block (3-weeks each)						
	1	2	3	4	5	6	7
Ambient:							
Temperature.....°F..	58	60	59	62	69	73	78
Relative humidity.....percent..	44	44	44	50	54	64	67
Hen:							
Average age.....days..	350	372	395	419	442	464	485
Average weight.....lbs./hen..	6.64	6.81	6.58	7.35	6.75	6.83	6.49
Eggs:							
Production.....percent..	72	74	74	69	62	73	60
Size of eggs.....oz./doz..	26.8	27.6	25.7	27.8	27.1	25.3	26.2
Feed consumption.....lbs./day/10 hens..	3.31	3.04	2.65	2.56	2.56	2.82	2.67
Feed conversion.....lbs. feed/lb. eggs..	3.29	2.86	2.67	2.56	2.93	2.93	3.26
Water consumption.....lbs./day/10 hens..	6.56	6.04	5.36	5.83	5.45	5.77	5.38
Water to feed.....ratio..	1.98	1.99	2.02	2.28	2.13	2.05	2.01
Fecal production.....lbs./day/10 hens..	5.16	4.67	4.26	4.72	4.38	4.68	4.84
(Water + feed) to feces.....ratio..	1.91	1.94	1.88	1.75	1.83	1.84	1.66

TABLE 10.--Egg data of caged New Hampshire X Cornish Cross laying hens before, during, and after each test block

Test block	Temp.	Group	Incubated eggs		Egg production		
			Fertility	Hatchability	Before	During	After
	°F.		Pct.	Pct.	Pct.	Pct.	Pct.
1	52	A	(1)	(1)	64	75	77
	32	B	(1)	(1)	62	72	72
	56	C	(1)	(1)	64	74	71
2	62	A	92	80	76	75	70
	21	B	86	74	78	61	60
	57	C	84	90	77	76	65
3	71	A	88	74	75	59	69
	43	B	87	82	76	56	71
	62	C	89	84	77	75	71
4	61	A	97	91	69	68	63
	31	B	100	94	69	50	51
	63	C	95	93	62	68	64
5	44	A	86	83	68	63	48
	23	B	92	88	70	50	57
	64	C	97	79	71	61	57
6	70	A	92	79	62	55	45
	50	B	92	75	65	60	58
	73	C	94	81	65	68	56
7	71	A	77	71	54	54	37
	61	B	74	80	62	49	38
	77	C	82	79	61	65	57

<sup>1</sup> No test made.

The ratio of drinking water to feed (table 8) increased uniformly from 1.38 to 1 at 21° F. to 1.94 to 1 at 71° F. The ratio for Group C hens (table 9) remained about 2 to 1. This ratio increased from low to high temperatures. Differences in egg production, age and live weights and other variables may affect this ratio slightly at a given temperature level.

The fecal production rate varied with feed and water consumption as well as egg production. The fecal production of hens in the calorimeters averaged from 3.3 to 5.0 pounds per day for 10 hens, while Group C remained fairly constant between 4.3 to 5.2 pounds per day for 10 hens.

The ratio of feed plus water to fecal production was about 1.6 to 1 at 21° and 32° F. and remained about 1.7 to 1 between 40° and 70° F. The ratio for Group C hens ranged from 1.7:1 to 1.9:1. These ratios were about equal to ones obtained for caged Rhode Island Reds. The ratios for caged Single Comb White Leghorns was 1.7 to 1 at 30° F. and increased thereafter to 2 to 1 at 70° F.

Table 10 shows that the insemination technique and the use of pooled semen were good.

Except for 3 tests within Group B (21°, 23°, and 31° F.), appendix figure 7 shows that body weight was practically unaffected within the range of temperatures tested. In nearly all test blocks the hens lost a little weight during the first week or so of each test, suggesting that movement and handling of the hens from the selection pool to the environment of the calorimeters may have affected them.

## Breed Differences in Heat Production of Individually Caged Laying Hens

Certain breed differences might be expected due to differences in egg production, size, feathering, activity, and perhaps other physiological factors. A regression analysis of caged hen studies failed to show a significant relation between egg and heat production. This was in accord with other studies (4, 5). The only remaining source of breed variation on which direct measures were made was size.

Appendix figure 8 shows that the caged New Hampshire x Cornish Cross produced the least latent heat per unit body weight, that the Single Comb White Leghorns produced the most, and that the Rhode Island Reds an intermediate amount. The Single Comb White Leghorns produced about 100 percent more latent heat per unit body weight between 22° and 70° F. than the New Hampshire x Cornish Cross. Thus, it would appear that Leghorns, which dissipated much more heat by evaporative cooling than the Rhode Island Reds and the New Hampshire x Cornish Cross, were better adapted to high temperature. Fox (8), Lee (17), and Hillerman (11) showed the continued persistence of White Leghorns to drink water at high temperature, but did not associate it to increased latent heat production.

Generally the Leghorns dissipated more sensible heat per unit weight than the other breeds. Thus, it would appear that Leghorns were the least protected against low temperature and probably the most affected by it as Hutt (15) has indicated. The Rhode Island Reds were able to protect themselves at temperatures below 40° F. as indicated by decreased sensible heat dissipation. Furthermore, at night when all three breeds were resting, the Rhode Island Reds dissipated the least sensible heat.

Appendix figure 9 shows heat data directly related to unit body surface area were calculated as follows:

$$\text{Area (square centimeters)} = 9.85 \times W^{0.67},$$

where W is in grams live weight (1).

This analysis tended to reduce breed differences. The high value at 84° F. for Single Comb White Leghorns may have been due to increased activity following prolonged exposure at 94° F.

This summary on the breed differences in heat production by weight and body surface area should not be extrapolated very much below or beyond the average weight of the test hens.

### Hens on Litter

#### Rhode Island Reds

Heat and Moisture Production. --The heat data of hens on litter (Appendix figures 10 and 11) showed that day to day variations at low temperatures were small, but at temperatures around 90° F., the sensible heat varied as much as plus or minus 5 Btu/hr/hen, while the latent heat varied about plus or minus 3 Btu from the mean values.

At 90° F. and with litter moisture constant at 25 percent dry basis (20 percent wet basis), the average latent heat production of Rhode Island Reds on litter, including latent heat from the litter, was 19 Btu/hr/hen more than the average for caged hens of that breed whose droppings were caught in oil (table 11). This difference was mainly attributed to drying of litter and droppings. This difference in latent heat was equivalent to a daily evaporation of about 4.4 pounds of water from a calorimeter containing 10 hens which was determined as reasonable in water balance calculations.

TABLE 11.--Comparison of heat production between on-litter and cage studies of Rhode Island Red laying hens

Test	Ambient		Hen	Litter		Heat/Production, Btu/Hour/Hen					
	Temperature	Relative humidity	Average weight	Dry basis	Wet basis	Day			Night		
						Sensible	Latent	Total	Sensible	Latent	Total
	°F.	Pct.	Lbs.	Pct.	Pct.						
On-litter.....	18-22	82-96	5.2	130	<sup>1</sup> 56.5	32	17	49	23	16	39
Caged.....	25	70	5.0	---	---	34	6	40	26	5	31
On-litter B <sup>2</sup> .....	33	70	5.5	75	42.9	32	22	54	21	21	42
On-litter A <sup>3</sup> .....	30	75	5.1	100	50	32	17	49	24	17	41
Caged.....	30	85	5.5	---	---	37	8	45	28	7	35
On-litter <sup>2</sup> .....	42	80	5.5	50	<sup>2</sup> 33.3	23	22	45	21	21	42
Caged.....	42	85	5.5	---	---	41	10	51	28	9	37
On-litter.....	90	70	5.0	25	20	7	35	42	9	33	42
Caged.....	90	36	5.0	---	---	7	16	23	5	14	19

<sup>1</sup> Data from period litter stabilized at 56.5 percent for 13 days.<sup>2</sup> Litter not stabilized in moisture content.<sup>3</sup> Litter moisture slowly rising, 17 percent dry basis in 16 days.

Between 18° and 22° F., 2 Btu of the day sensible heat were used to dry the litter (difference in latent heat between caged and on-litter birds--table 11) and 9 Btu of day latent heat were derived from drying and decomposition of litter. The differences in latent heat between caged and on-litter-birds--table 11 were used for these determinations. Similar calculation at night showed that 3 Btu of the night sensible heat were used to dry litter and 8 Btu of night latent heat were derived from litter.

Hen Performance Data. --No conclusive statement on percent egg production relative to temperature (appendix figures 10 and 11) could be made.

The size of eggs of Group A hens at 90° F. was 8 grams per egg smaller than Group B at about 20° F. (table 12). In the temperature reversal test at the end of the experiment when Group B hens were raised to about 84° F. and Group A hens lowered to 40° F., the eggs of Group B became 11 grams smaller and the eggs of Group A became 3 grams larger (see also table 13).

TABLE 12.--Data on eggs obtained from Rhode Island Red hens on litter

Date	Group A				Group B			
	Temperature	Average weight per egg	Haugh units <sup>1</sup>	Shell thickness <sup>2</sup>	Temperature	Average weight per egg	Haugh units <sup>1</sup>	Shell thickness <sup>2</sup>
	°F.	G.		In.	°F.	G.		In.
March 30-April 10...	90	52.3	79	13.4	22	62.7	70	15.2
April 11-April 15...	90	54.6	74	13.6	22	64.1	64	15.3
April 16-April 21...	90	56.5	77	13.5	22	62.9	74	14.8
April 22-April 28...	90	55.3	81	13.8	20	62.9	76	15.6
April 29-April 30...	90	58.6	83	14.3	20	65.1	80	15.7
April 30-May 8.....	90	56.7	80	14.1	20	65.1	75	15.3
May 9-May 13.....	90	57.2	78	14.4	20	64.8	77	16.1
May 14-May 22.....	90	56.2	78	14.4	37	64.3	77	16.0
Average.....	90	55.9	79	13.9	23	64.0	74	15.5
June 3-June 11.....	40	55.7	---	---	84	53.1		
June 12-June 18.....	32	58.4	---	---	86	56.4		

<sup>1</sup> Haugh units - high values indicate high egg quality.<sup>2</sup> Shell thickness in 0.001 inch thickness.

The eggs from hens in Group A (high temperature group) consistently showed higher Haugh units than those of Group B (low temperature group). The average shell thickness of eggs of Group A hens was 0.0139 inch, while Group B hens averaged 0.0155 (table 12.). However, egg shells of Group A hens appeared to get thicker as the test progressed. There was no difference in small and large meat spots nor in small and large blood spots in the eggs. These values were obtained from an average sampling of 31 eggs per week. These relations of temperature and egg quality were consistent with results obtained by Warren (25).

The body weight of Group A hens (high temperature group) averaged 5.9 pounds at the beginning of the test and gradually decreased until it was about 5 pounds after 20 days of exposure--a loss of 18 percent. Thereafter, the weight remained very nearly constant--even when hens were placed in Calorimeter B at a lower temperature (appendix figure 10). In contrast, at low temperatures, the average weight (appendix figure 11) of Group B hens remained about constant at 5.3 pounds and when the temperature was changed from about 20° to 65° F., the Group B hens gained about 0.3 pound, only to lose it when the temperature was later increased to 86° F. High air temperature apparently caused weight losses among these birds.

TABLE 13.--Calorimeter data of Rhode Island Red hens on litter

Item	Month of test									
	Jan. 26- Feb. 25	Feb. 25- Mar. 16	Mar. 16- Apr. 21	June 1-8	June 9-19	Feb. 15-27	Mar. 7-22	Apr. 8- May 6	May 23- Jun. 1	June 7-19
Group.....	A	A	A	A	A	B	B	B	B	B
Ambient:										
Temperature.....° F..	83	91	91	46	33	41	34	21	44	85
Relative humidity.....percent..	47	70	67	82	77	75	69	82	81	64
Air flow to calorimeter..lbs./hr..	45	48	48	48	44	48	48	47	46	48
Hen:										
Average age.....days..	336	361	388	451	460	347	369	407	441	459
Average weight.....lbs./hen..	5.70	5.32	5.08	5.24	5.16	5.51	5.48	5.24	5.49	5.36
Eggs:										
Production.....percent..	72	66	46	41	44	55	55	36	36	66
Size of eggs.....oz./doz..	24.4	22.6	21.9	23.2	24.7	25.3	24.9	25.3	24.6	23.8
Feed consumption..lbs./day/10 hens..	2.98	2.24	2.20	3.38	3.76	2.97	3.38	3.70	4.03	2.67
Feed consumption <sup>1</sup> .....lbs./day/10 hens..	2.93	2.80	2.42	2.40	2.45	2.70	2.70	2.36	2.38	2.80
Feed conversion..lbs. feed/lb. eggs..	3.24	2.87	4.19	6.74	6.64	4.10	4.70	7.44	8.84	3.12
Oyster shell consumption...lbs./day/10 hens..	.18	.14	.09	.09	.09	.12	.13	.12	.10	.15
Water consumption..lbs./day/10 hens..	5.91	6.38	7.08	5.35	5.40	5.14	6.44	6.52	7.18	7.52
Water to feed.....ratio..	1.98	2.85	3.22	1.58	1.44	1.73	2.00	1.76	1.78	2.82
Water input-output balance.....lb./10 hens..	±.54	±.38	±.29	±.37	±.17	±.20	±.50	±.81	±.73	±.37

<sup>1</sup> Published in Poultry Nutrition, 4th ed. W. Ray Ewing.

Although no respiration count was made, a rapid rate was observed during the first 20 days of test at 90° F. Thereafter, the respiration rate was slower.

#### New Hampshire x Cornish Cross

Heat Production.--Heat production of the New Hampshire x Cornish Cross on litter is shown in appendix figures 12 and 13 and in tables 14 and 15. At comparable temperatures, the heat production of the two groups was different. This may be attributed to differences in size of hens, egg production, and litter moisture content and decomposition. However, as temperatures increased from 65° to 75° F., sensible heat decreased and latent heat increased for both.

TABLE 14.--Comparison of heat production between on-litter and cage studies of New Hampshire X Cornish laying hens

Temperature	Ambient		Hen	Heat/Production, Btu/hour/hen					
	Relative humidity	Housed	Average weight	Day			Night		
				Sensible	Latent	Total	Sensible	Latent	Total
°F.	Pct.		Lbs.						
66	83	on litter, 35 percent dry basis	5.5	26	23	49	29	20	49
66	75	in cage	5.5	30	10	40	25	8	<sup>1</sup> 33
65	77	on litter, 39 percent dry basis	6.0	24	30	54	27	22	49
65	75	in cage	6.0	32	10	42	27	8	<sup>1</sup> 35
75	74	on litter, 33 percent dry basis	5.6	23	25	48	20	22	42
75	--	in cage	5.6	24	11	35	22	7	<sup>2</sup> 29
75	75	on litter, 33 percent dry basis	6.1	23	33	56	24	23	47
75	--	in cage	6.1	26	11	37	24	7	<sup>2</sup> 31

<sup>1</sup> Sensible heat data calculated from interpolated data of hens weighing 7 lbs.<sup>2</sup> Sensible heat data calculated from extrapolated data of hens weighing 7 lbs.

TABLE 15.--Calorimeter data of New Hampshire X Cornish hens on litter

Item	Month of test						
	Nov. 1- Dec. 2	Nov. 24- Dec. 13	Dec. 5-19	Dec. 24- Jan. 6	Dec. 26- Jan. 11	Jan. 17-24	Jan. 11-27
Group.....	A	B	A	B	A	B	A
Ambient:							
Temperature.....° F.	63	65	63	74	74	73	74
Relative humidity.....percent..	85	82	78	80	75	74	74
Air flow to calorimeter.....lbs./hr..	46	46	46	49	47	49	47
Hen:							
Average age.....days..	257	270	278	298	300	315	318
Average weight.....lbs./hen..	6.0	5.5	6.0	5.6	6.1	5.7	6.1
Eggs:							
Production.....percent..	71	60	69	52	63	37	58
Size of eggs.....oz./doz..	25.1	23.5	25.3	24.2	24.8	24.3	25.3
Feed consumption.....lbs./day/10 hens..	3.07	2.56	3.21	2.65	2.88	2.50	2.58
Feed consumption <sup>1</sup> .....lbs./day/10 hens..	3.00	2.75	2.98	2.68	2.89	2.48	2.86
Feed conversion.....lbs. feed/lb. eggs..	3.30	3.34	3.51	4.08	3.72	5.33	3.37
Cyster shell consumption....lbs./day/10 hens..	.20	.12	.15	.10	.11	.08	.08
Water consumption.....lbs./day/10 hens..	6.07	4.57	6.02	4.88	6.03	4.96	6.51
Water to feed.....ratio..	1.98	1.78	1.88	1.84	2.09	1.98	2.52
Water input-output balance.....lb./10 hens..	±.23	±.20	±.32	±.16	±.35	±.21	±.40

<sup>1</sup> Published in Poultry Nutrition, 4th ed. W. Ray Ewing.<sup>2</sup> Temperature was raised in both calorimeters to 75° F. from Dec. 21.

Comparisons of caged and "on-litter" hens (table 14) showed that, at 65° F., the sensible heat required to maintain a 35 to 39 percent dry basis litter moisture content and to dry the droppings table was apparently 13 to 25 percent of the sensible heat produced by the hens. These comparisons also indicated that about 13 to 20 Btu/hr/hen of the latent heat came from the litter. At 75° F., about 10 percent or 2 Btu of the day sensible heat was evidently used to dry litter and droppings on the table and about 14 to 22 Btu/hr/hen of the latent was derived from the litter and droppings.

At night the sensible heat of caged hens dropped about 5 Btu at 65° F., or about 17 percent from the day value. However, the data of hens on litter showed that sensible heat increased at night by about 3 Btu from the day value. The aeration of the litter from the stirring of the manure by the hens during the day and the undisturbed condition of the material at night may have contributed to accelerated decomposition.

Hen Performance Data. -- Within a given temperature condition there was a gradual decline in egg production in both calorimeters as tests progressed. There was practically no weight change of hens in either calorimeter. The experimental data on feed consumption in table 15 were very close to data published by Ewing (7).

When given oyster shells ad libitum (in addition to limestone flour in the standard mash), the hens laying at 70 percent rate consumed oyster shells at the rate of 0.15 to 0.28 lb/10 hen/day, and at 50 percent egg production they consumed about 0.1 lb/day.

Near the end of tests water consumption in both calorimeters increased which may have been due to consumption of litter material containing superphosphate, used to reduce ammonia. By January 25 in Calorimeter B there was about 14 1/2 pounds of superphosphate in 150 pounds of wet litter, while in Calorimeter A there was about 17 pounds of superphosphate in 175 pounds of wet litter.

#### Ammonia Dissipation and Litter Moisture

The hens were observed to jerk their heads when air contained 75 p.p.m. of ammonia. Observations showed that hens were apparently not bothered by 40 p.p.m. of ammonia. Generally the minimum organoleptical detection point of ammonia in the air by man is around 15 p.p.m. At 25 to 35 p.p.m. one's eyes begin to burn and tears flow. The production of ammonia depends on the amount of fecal matter in the litter, litter moisture and temperature, the amount of aeration of litter, and possibly the porosity of the litter.

With bird density of 3-1/2 sq. ft. per hen and beginning with fresh litter, about 10 days' accumulation of fecal matter in the litter was needed to produce ammonia in the chamber and in these tests approximately one third of fecal deposition was deposited on the droppings table.

When air temperatures were below 32° F., there was no noticeable ammonia. Above 32° F., the ammonia production became noticeable.

Generally, ammonia production ceased near 21 to 25 percent dry-basis and began at a litter-moisture content above 29 percent dry-basis (22-1/2 percent wet-basis) continuing even when the litter moisture content was as much as 63 percent wet-basis.

Limited data showed superphosphate was needed more frequently and in greater amounts between 65 and 75° F. than at 80° F. A weekly application of 9.5 pounds of superphosphate to 100 square feet of litter was sufficient to keep ammonia near 15 p.p.m. at 80° F. Between 65° and 75° F., about 6 to 8 pounds of superphosphate per 100 square feet of litter were required every 3 days. Roughly an additional 2 to 3 pounds of superphosphate per 100 square feet of droppings table were required.

With 1 c.f.m. per hen ventilation rate, the following stabilized litter moisture content was obtained at various air temperature and relative humidity levels:

<u>Temperature and relative humidities</u>		<u>Litter Moisture Content (dry basis)</u>	<u>Remarks</u>
°F.	Percent relative humidity	Percent	
90	70	25	Dusty.
	55	21	Do.
72-75	75	33	Somewhat dusty.
66	80	36	Almost dust free-- easily worked up by hens.
63-65	80	40	Almost dust free-- easily worked up by hens.

The weekly removal and moisture sampling of fecal matter on the droppings table showed about 34 percent dry-basis moisture content at 65° and 75° F. air temperatures of the calorimeters.

## SUMMARY

The cage studies of hens in the calorimeters showed at least three general changes in heat production of caged laying hens. At the high temperature (above 90° F.), the sensible heat approached zero and the latent heat accounted for almost all of the total heat. At moderate temperatures (40° to 75° F.), both sensible and latent heat remained about constant and latent heat accounted for 20 to 30 percent of the total. At low temperatures (below 40° F.), the sensible heat averaged 7 to 10 times the latent, and the latent approached a common value of about 5 to 6 Btu/hr/hen, irrespective of breed, weight, age, and egg production.

On unit weight and unit surface area bases, Single Comb White Leghorns produced the greatest amount of heat (latent plus sensible) and New Hampshire x Cornish Cross produced the least. The heat loss of Rhode Island Reds fell in between the other two breeds tested.

The fact that Single Comb White Leghorns emitted the highest amount of latent heat per unit of body weight suggested a better developed evaporative cooling mechanism for that breed.

In caged hen studies the latent heat production, per unit weight and per unit body surface area of the bird, generally decreased with decreasing temperature. Near 20° F., irrespective of breed, both day and night latent heat approached 5 to 6 Btu/hr/hen or about 0.13 pound of water/day/hen. At air temperatures near 90° F., the moisture dissipation of Rhode Island Red and Leghorn caged hens increased to about 0.4 lb./day/hen.

Through comparisons of caged and on-litter hen data, estimates were obtained of the sensible heat required to dry litter. For example, at 65° F. about 13 to 25 percent of the day sensible heat production of hens was used to maintain a 35 to 39 percent (dry-basis) litter moisture, while at 75° F. about 10 percent of the sensible heat was used to maintain a 33 percent (dry-basis) litter moisture.

With hens on litter, moisture dissipation was about 0.40 pound of water/day/hen at about 20° F., and increased to about 0.75 pound of water/day/hen at about 90° F. (using Rhode Island Red hens). These values were obtained with about 1 c.f.m. air flow per hen and a bird density of 3-1/2 sq. ft. of floor area per hen.

With an air-flow rate of 1 c.f.m. per hen and bird density of 3.5 square feet per hen, the litter moisture content decreased almost linearly from a high of 40 percent dry-basis at 64° F. to about 23 percent at 90° F.

The heat and moisture dissipation data of these studies may be used for designing poultry houses. However, these data do not include heat and moisture from the usual "coned" droppings of caged birds.

At temperatures of 65° and 75° F., a superphosphate application of 6 to 8 pounds per 100 square feet of litter floor about every 3 days was sufficient to keep ammonia within tolerable limits. Slightly less was required at 80° F.

The average performance of the hens at the various temperatures were shown.

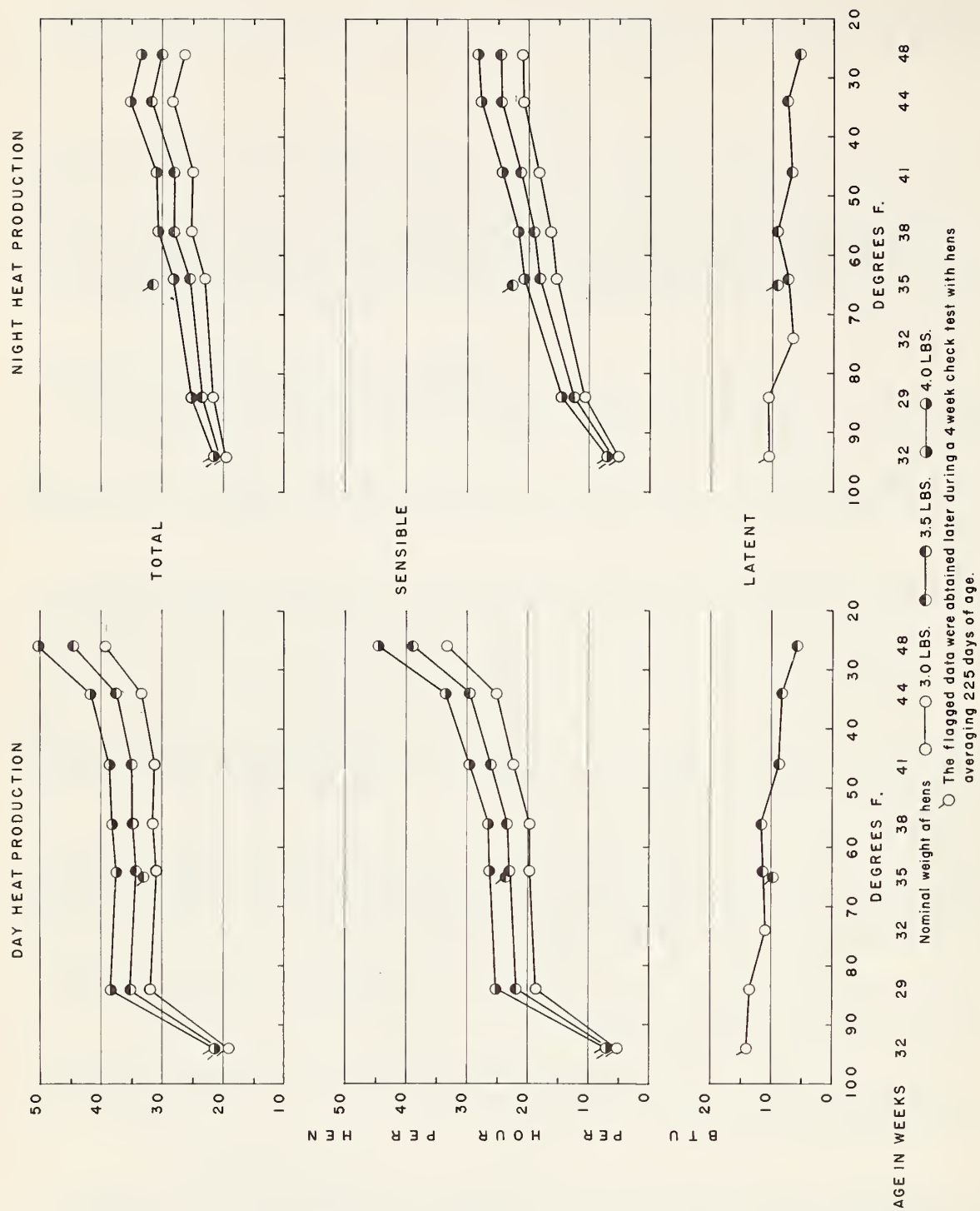


Figure 1. --Average heat production of Group A caged Single Comb White Leghorns at various temperature levels.

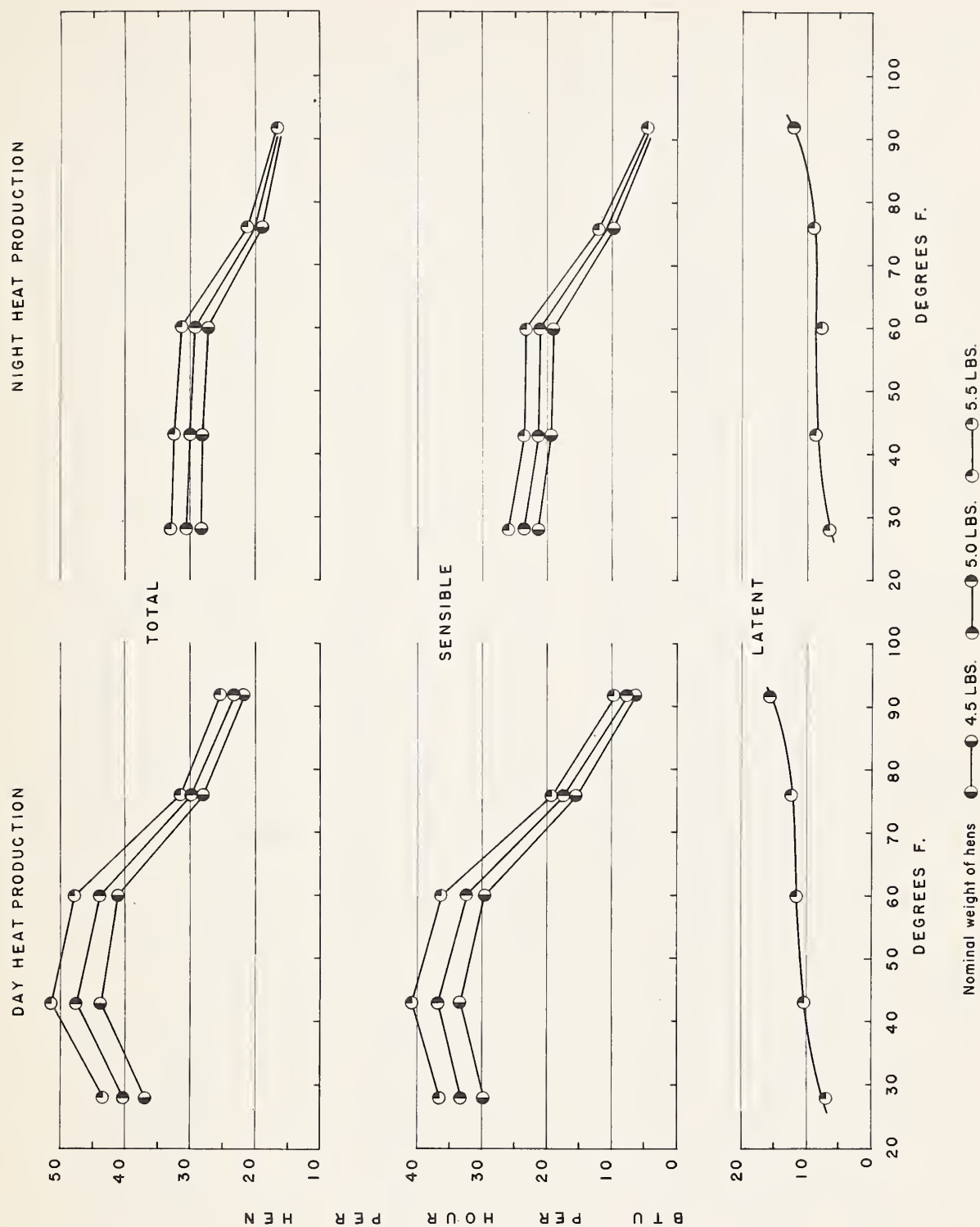


Figure 2. --Average heat production of Groups A and B caged Rhode Island Red hen at various temperature levels.

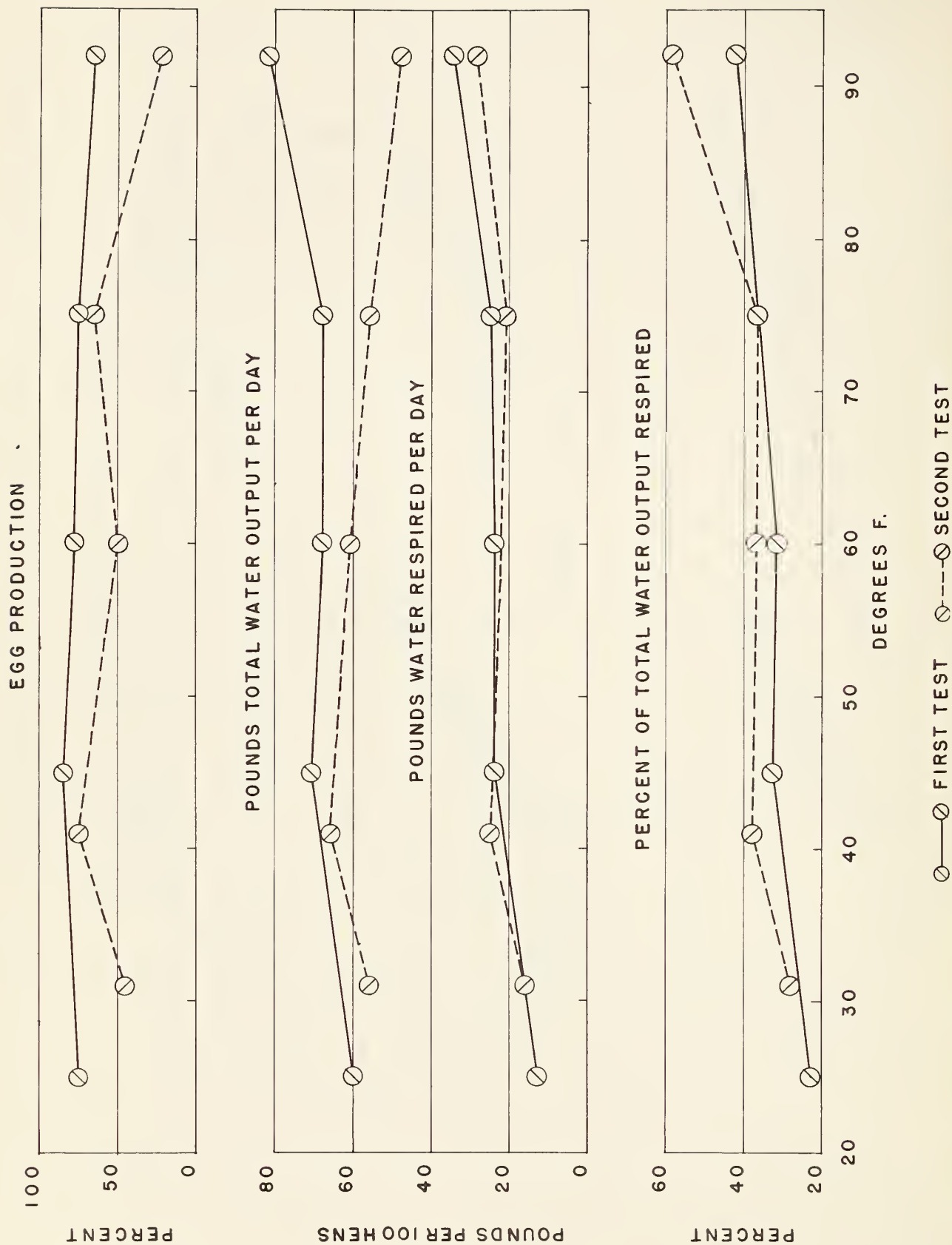


Figure 3.--Amount of moisture dissipated by 100 caged Rhode Island Red hens at various temperatures and corresponding egg production levels, total water output, and amount of water respired.

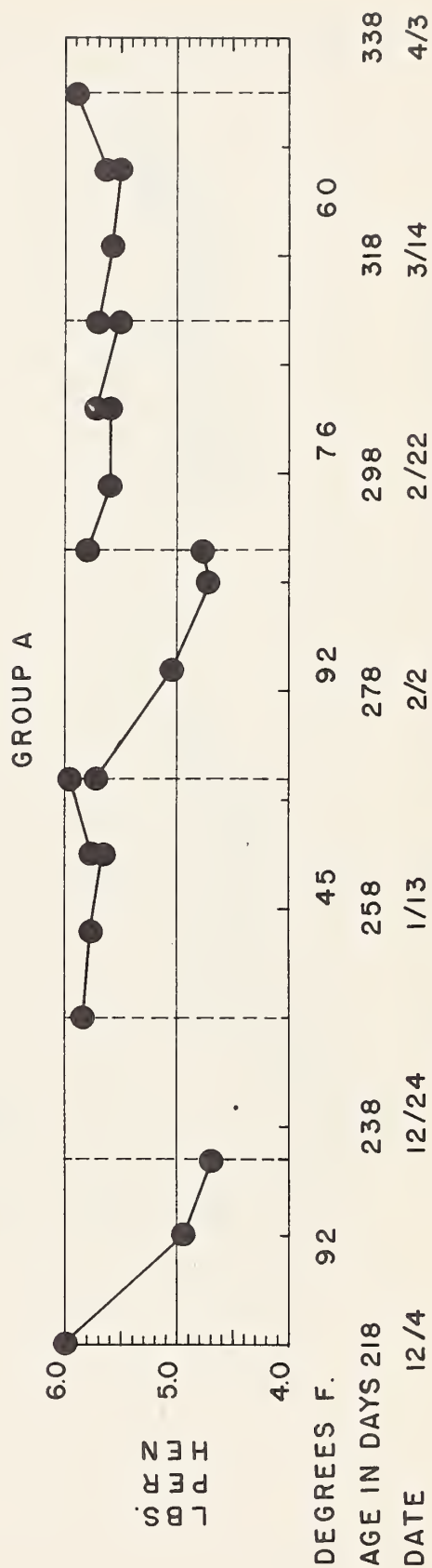
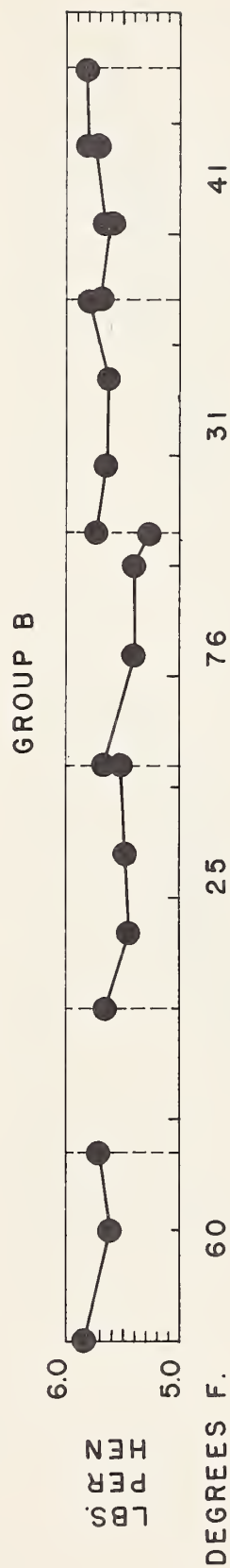
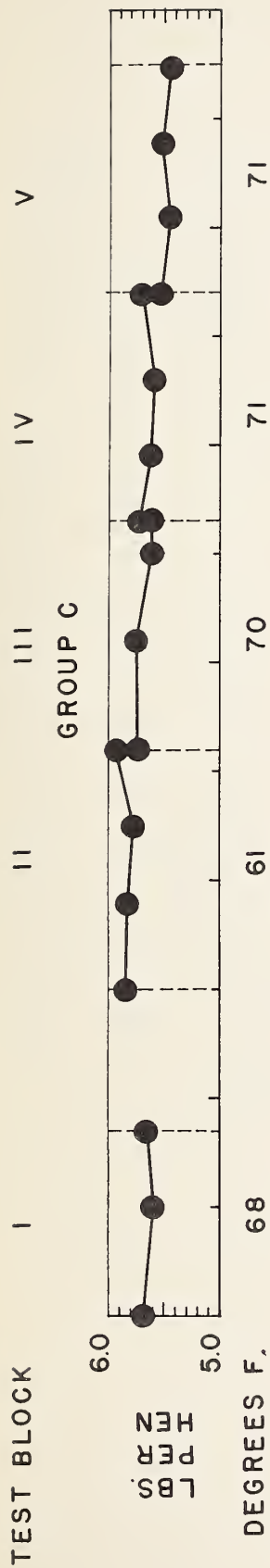


Figure 4. --Average body weight of caged Rhode Island Red hens.

Note: Two dots at the same time, within a block, resulted from a change due to removal of a hen from the group.

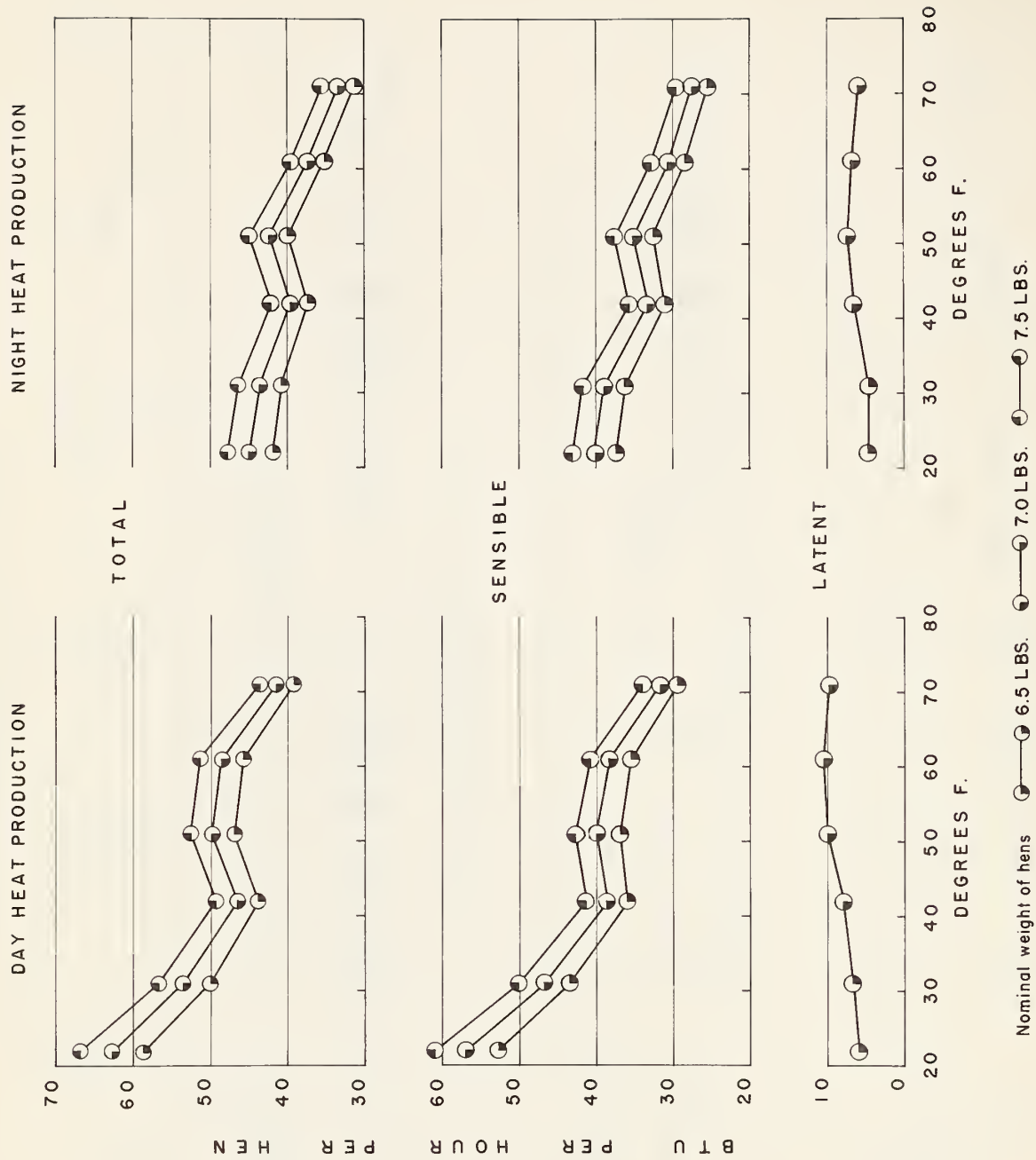


Figure 5. ---Average heat production of caged New Hampshire x Cornish cross laying hens at various temperature levels.

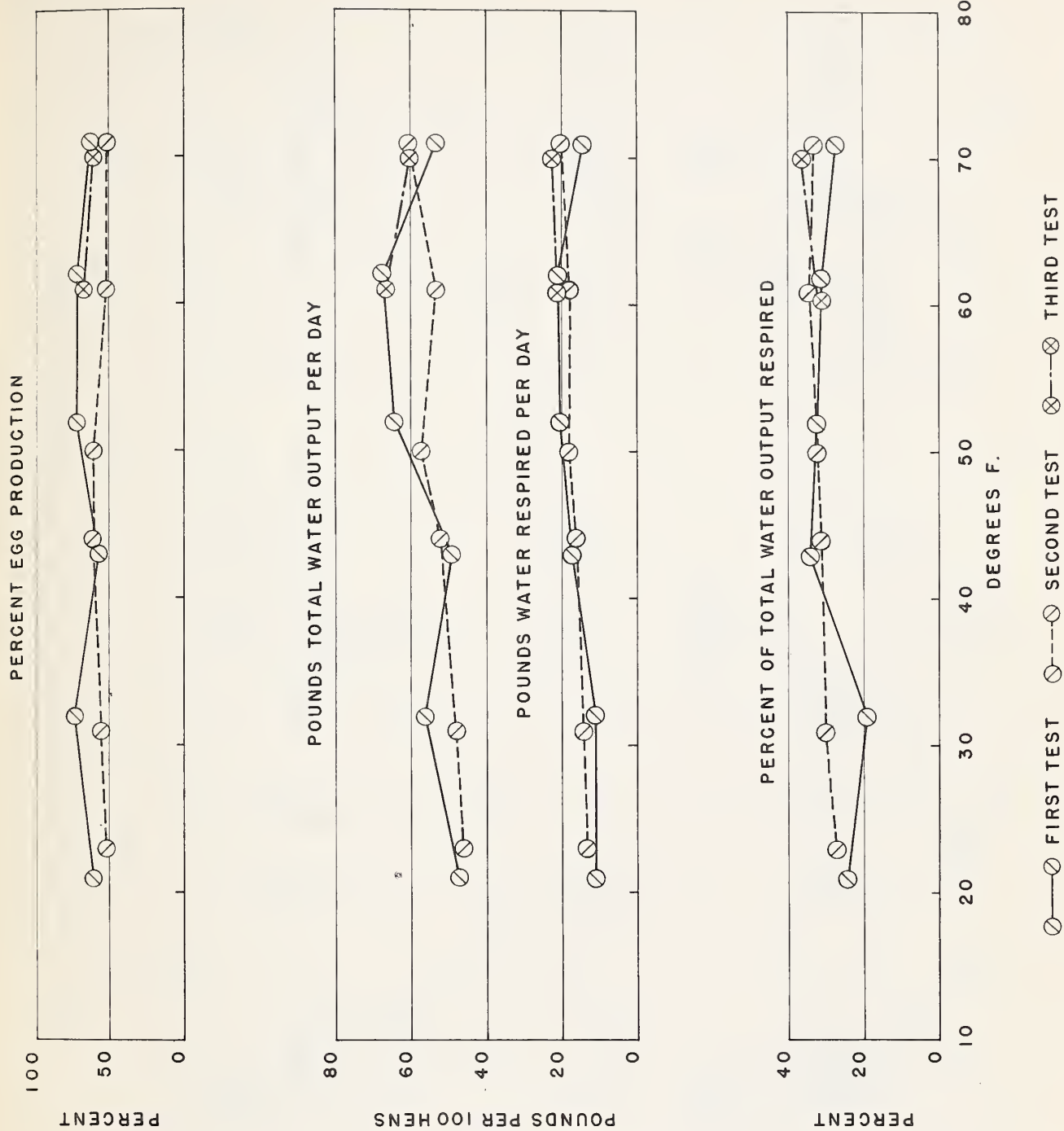


Figure 6. --Amount of moisture dissipated by 100 caged New Hampshire x Cornish cross hens at various temperatures and corresponding egg production levels, total water output, and amount of water respired.

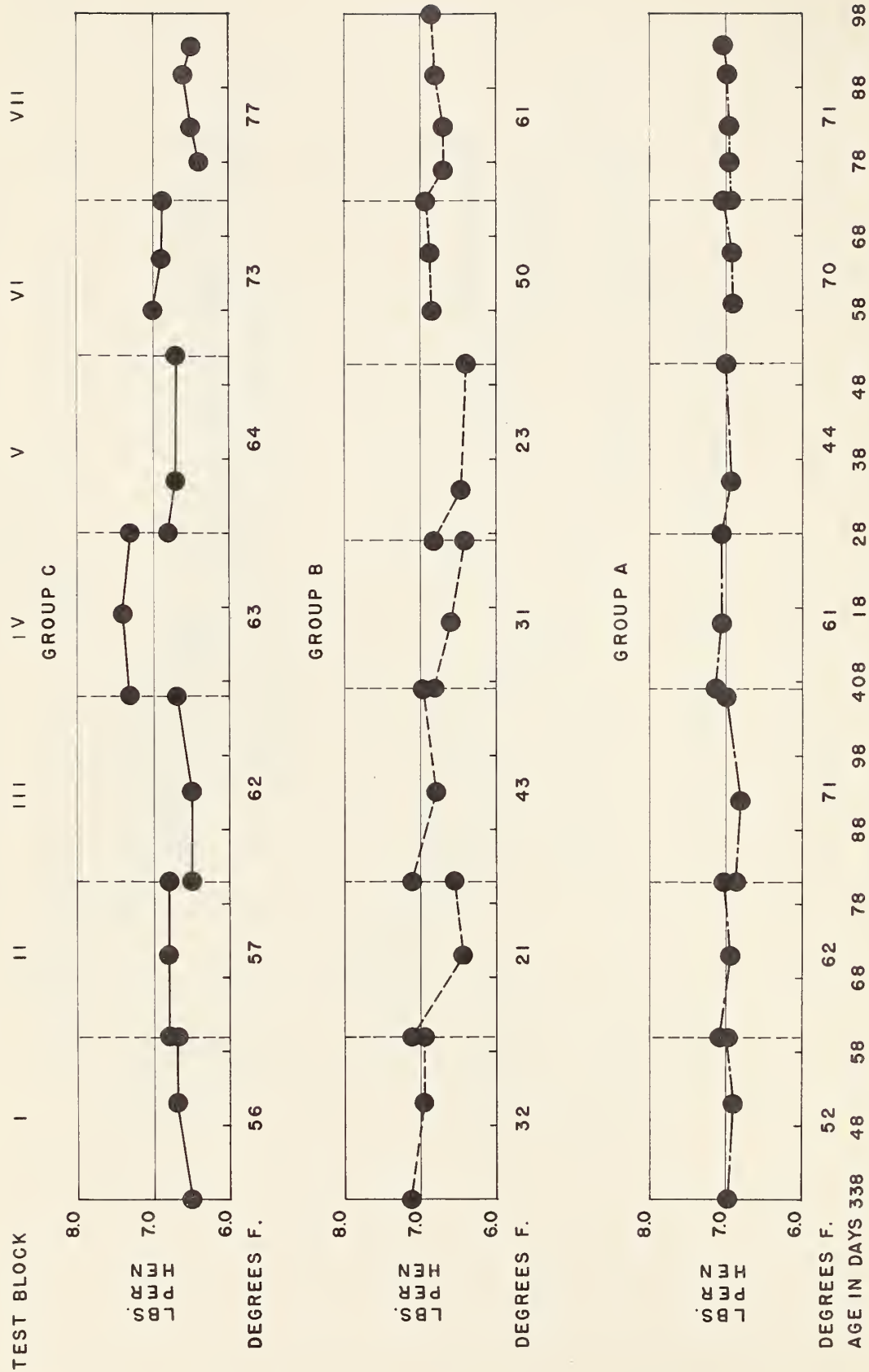


Figure 7. --Average body weight of caged New Hampshire X Cornish Cross laying hens.

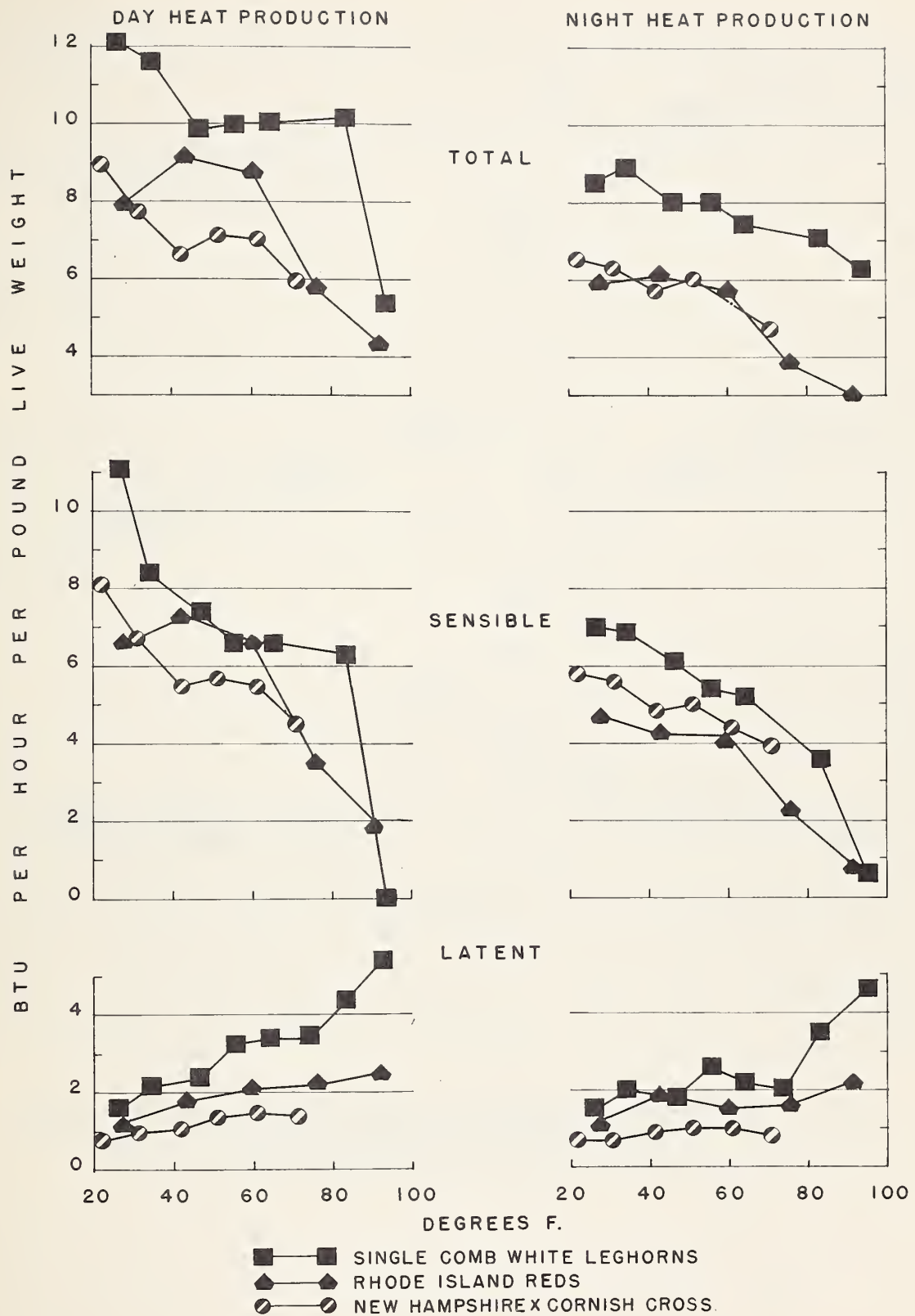


Figure 8. --Heat production characteristics based on per unit body weight of three breeds of caged laying hens at various temperature levels.

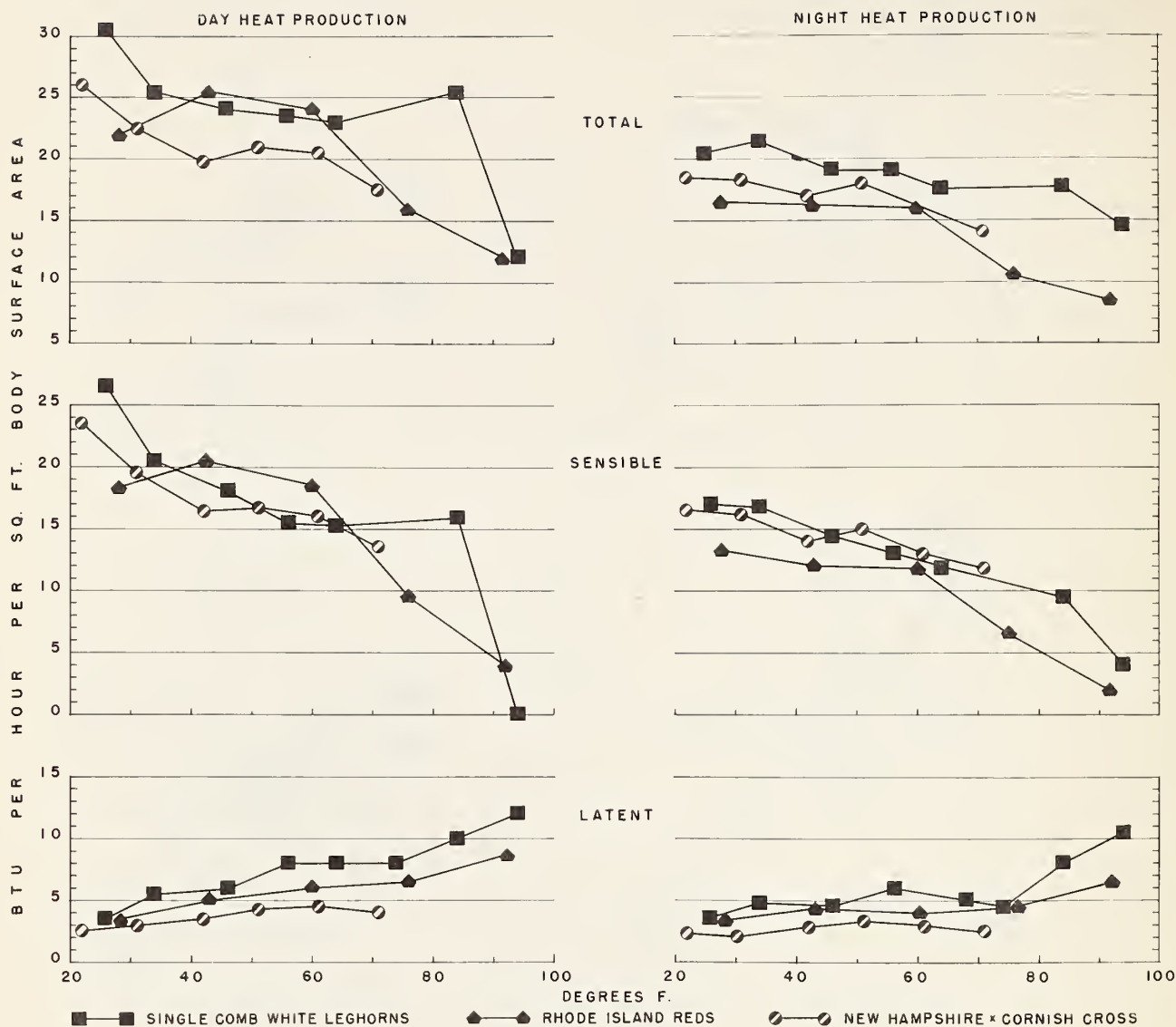


Figure 9.--Heat production characteristics based on per unit body surface area of three breeds of caged laying hens at various temperature levels.

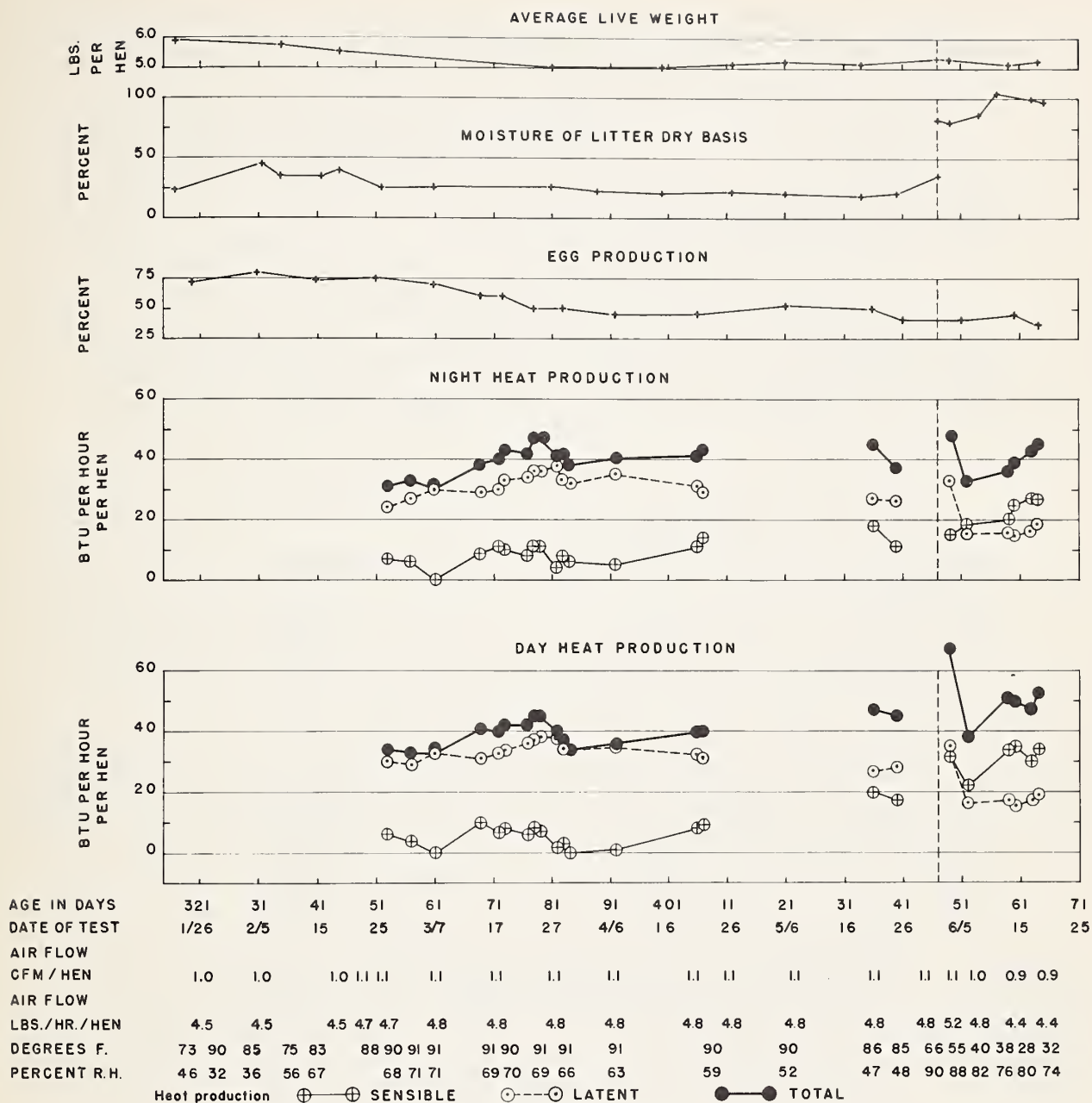


Figure 10. --Calorimeter data on Rhode Island Red hens on litter (Group A).

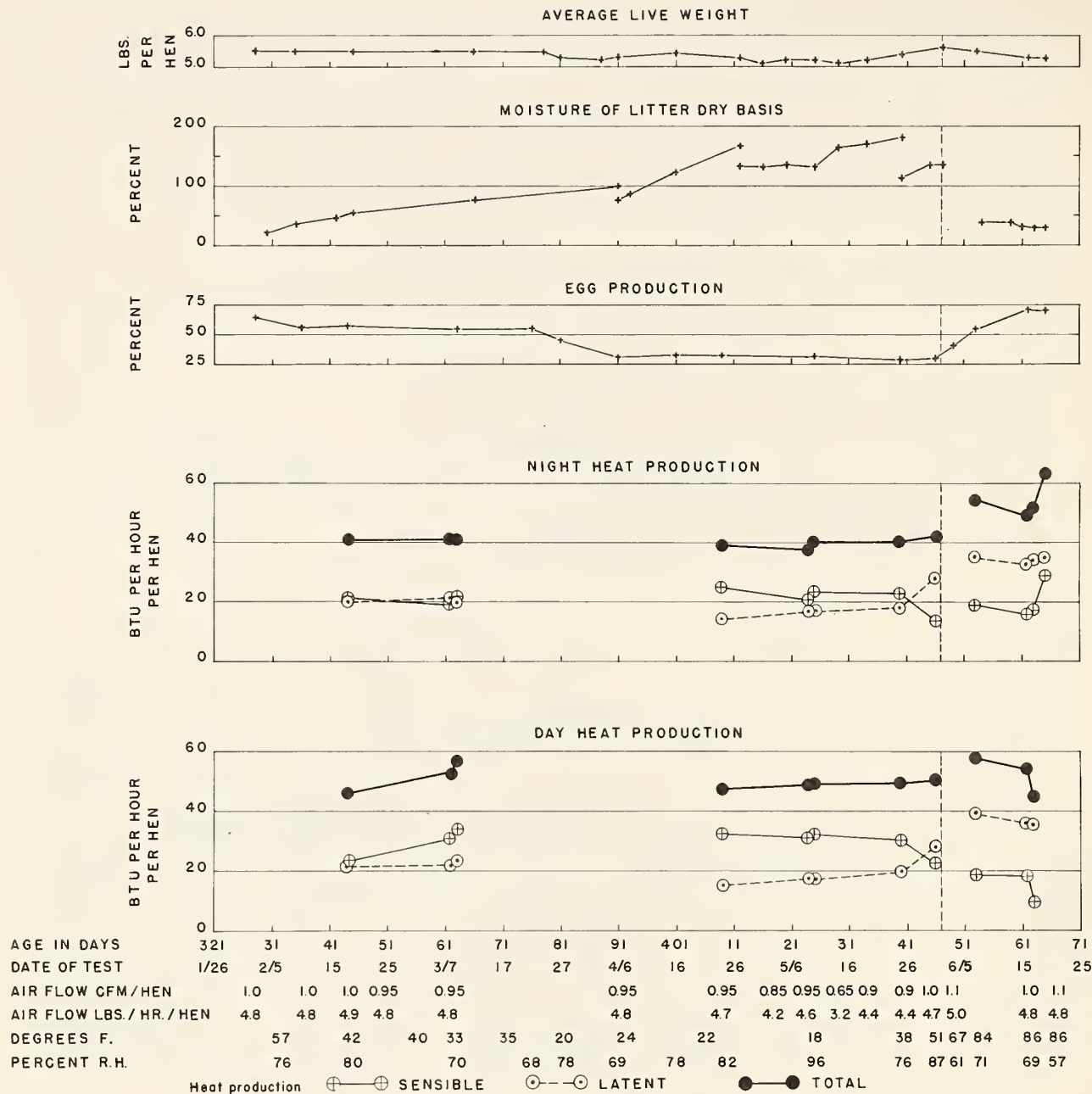


Figure 11. --Calorimeter data on Rhode Island Red hens on litter (Group B).

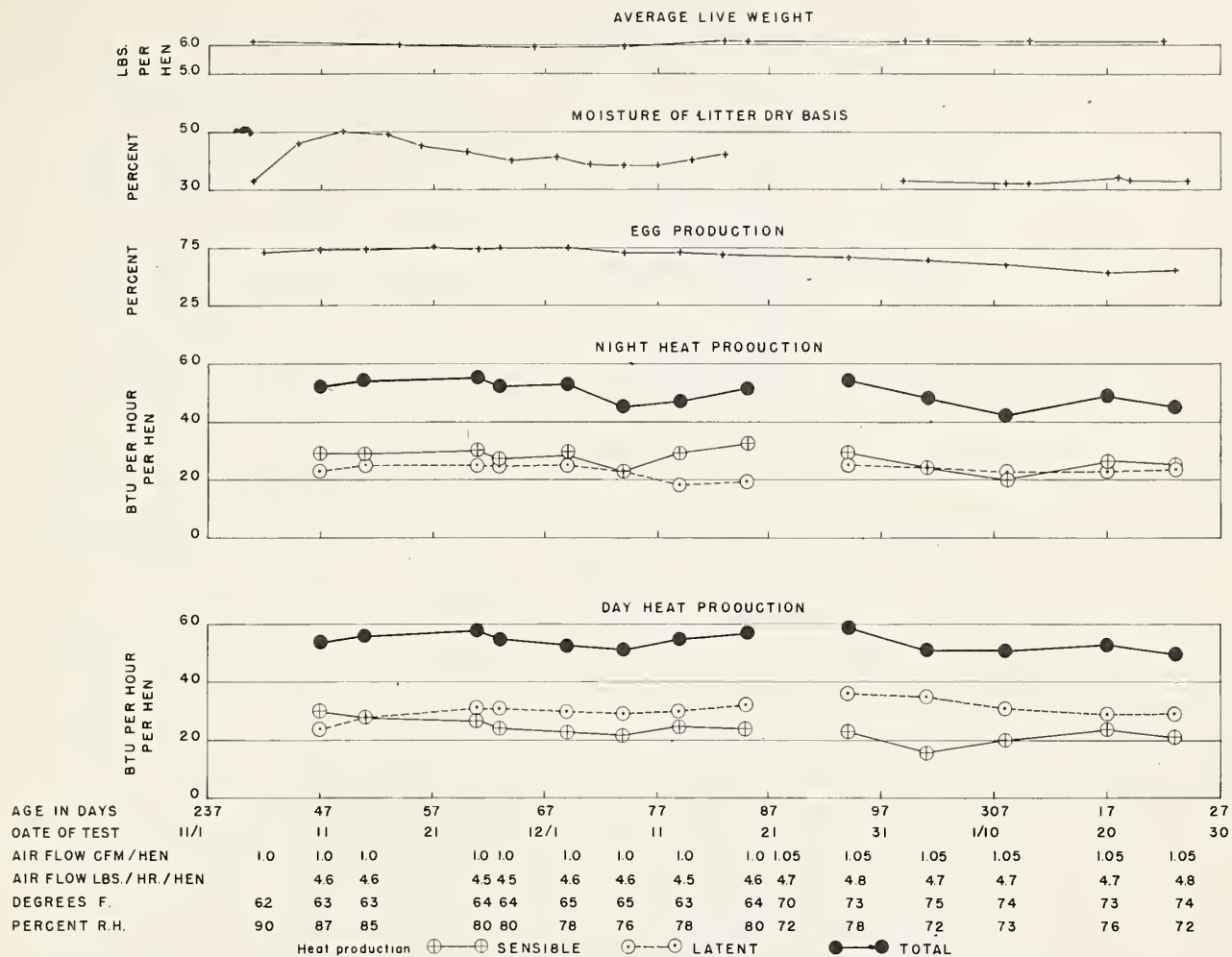


Figure 12. --Calorimeter data on New Hampshire X Cornish Cross hens on litter (Group A).

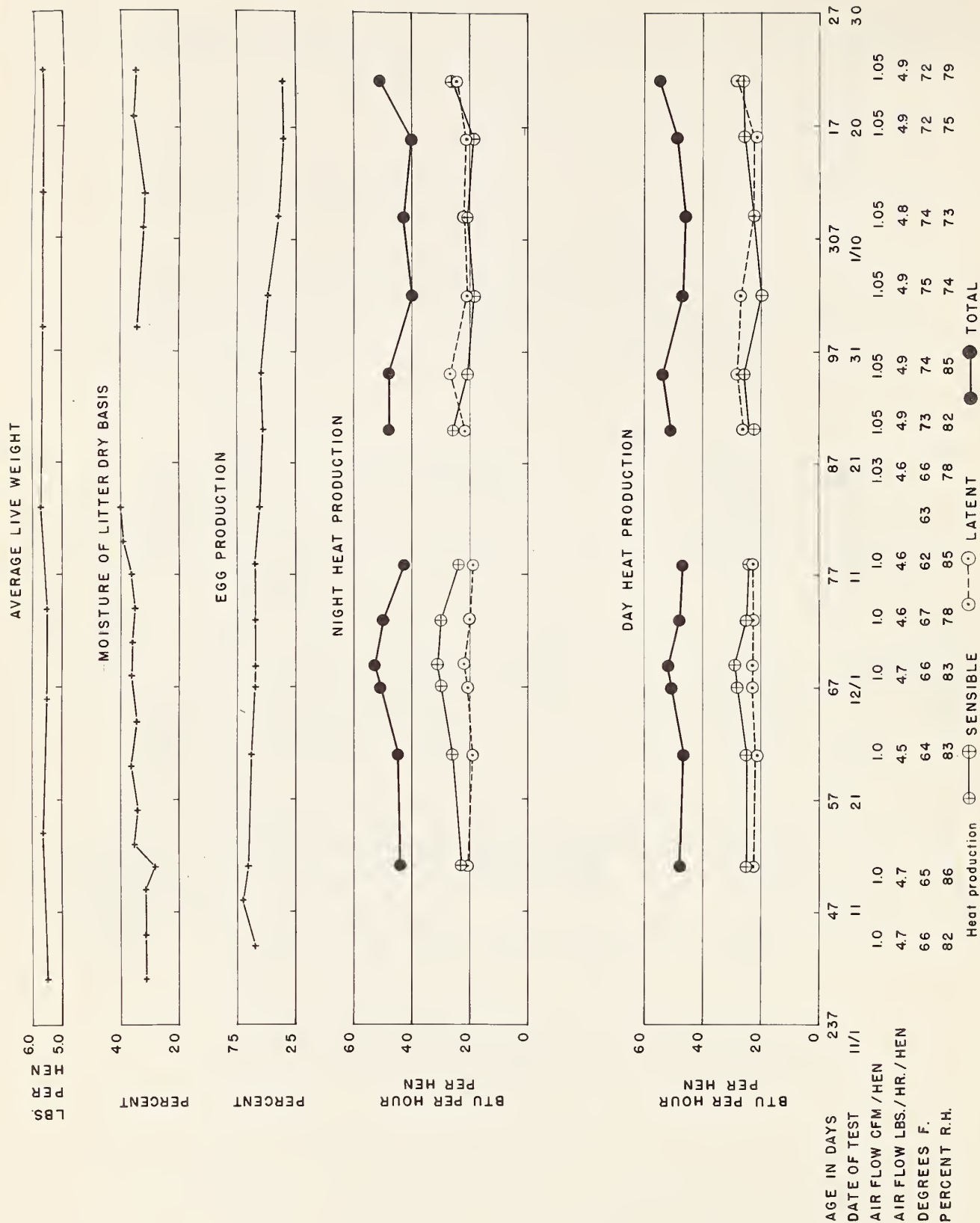


Figure 13. --Calorimeter data on New Hampshire X Cornish Cross hens on litter (Group B).

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